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NOTES

Overview

It is not a requirement for a welding inspector to be able to weld, neither does a welding inspector require an in depth knowledge of welding engineering, although some specific knowledge in these areas is essential. For certain contracts it is also necessary for a welding inspector to have a good working knowledge of other related subjects, e.g. radiographic interpretation and post-heat treatment.

The presence of welding inspectors during welding will almost certainly reduce the number of weld defects and metallurgical problems which could otherwise occur, which will in turn, reduce the overall number of failures in service. When an item has failed, it usually means that cracking or fracture has taken place.

There are many types of cracks associated with welds, some of which may initiate at the time of welding (process cracks) or years later (in-service cracks). In both these cases, stresses, metallurgical problems and existing weld defects may have contributed to the cause of the cracking.

Inspection philosophy

The duties of inspection personnel are essentially those inspection duties which the client or employer wants them to perform. A significant problem in industry is that different organisations use inspection personnel in different ways, or use inspectors for functions additional to inspection. For some, this has led to a misunderstanding as to the defined role of *inspection*.

The definition of inspection to EN 28402 : 1991 : Quality Vocabulary - "*Activities such as measuring, examining, testing, gauging one or more characteristics of a product or service and comparing these with specified requirements to determine conformity.*"

The definition of inspection to EN 45020 : 1993 : Standardization and Related Activities - "*Evaluation for conformity by measuring, observing, testing or gauging the relevant characteristics.*" ... "*Evaluation for conformity*" is defined in the standard as: "*Systematic examination of the extent to which a product, process or service fulfils specified requirements.*"

Inspection may be performed for *fitness for purpose* or *quality control* purposes, and may be carried out by the contractor, the client or a third party.

Inspection is not supervision and inspection is not a substitute for supervision.

It is not the duty of an inspector to deviate from *specified* requirements; generally speaking, if the specification is inadequate the work will be inadequate. Inspector qualification schemes do not require, or test for, a sufficient depth of engineering, technology or design knowledge which would enable an inspector to pass judgement on the correctness of an application specification. It could be argued that experienced *senior* inspectors may be in a position to take certain *engineering* decisions, but it is dangerous to generalise on this point.

An inspector (working solely as an *inspector*) is not there to provide solutions to problems.

Inspectors are taught never to deviate from the agreed specifications unless given written permission to do so from the client or supervisor.

Accurate reporting needs highlighting as an important duty for any inspector, but what constitutes a correct report can differ between organisations and projects. Who the inspector actually reports to is also an important consideration.

The term 'specification' relates here to any national or international specification(s), client specification(s), job specification(s) and welding procedure specification(s)

NOTES

It should be made clear to all workers, including inspectors, as to what is expected from them for the activities they are to perform - this is a basic quality assurance requirement.

This is not to say an inspector should not perform duties outside the scope of inspection, this may be acceptable providing the person is competent to perform the work and providing it has been made clear what is required from the outset.

Specific duties of a Welding Inspector

The main duty of a welding inspector is to check that all the welding and associated actions are carried out in accordance with the requirements of the agreed welding specification(s) relevant to the contract or work being carried out.

It is important for a welding inspector to know where to find relevant information, interpret the information and understand it.

Duties prior to welding:

1. Obtain all relevant documentation or ensure access to it:
 - a. relevant specification(s);
 - b. relevant procedures;
 - c. copies of welders test certificates (where applicable);
 - d. copies of drawings (where applicable).
2. Ensure welder qualification.
3. Correct material—type, condition, size (pipe/plate etc.).
4. Correct consumables—type, condition, size (filler material, gas, inserts etc.).
5. Correct equipment—certified where necessary.
6. Correct preheat (where applicable)
7. Assess/measure fit-up:
 - a. root face,
 - b. bevel angle,
 - c. root gap,
 - d. alignment,
 - e. seam offset (where applicable),
 - f. joint cleanliness.
8. Correct environment.
9. Ensure no undue stress is applied to the joint.

Duties during welding:

1. Check amperage, voltage, polarity.
2. Ensure correct welding technique—weld direction, run sequence.
3. Check welding time—time lapses and/or run out lengths (r.o.l.'s).
4. Ensure adequate cleaning between passes.
5. Correct interpass temperatures—minimum and/or maximum.
6. Check root internally (pipes) where access permits.
7. Check back gouged welds - amount gouged, shape of gouge, cleanliness of gouge (where applicable).

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Duties after welding:

1. Ensure weld is post cleaned.
2. Visual inspection of weld for defects, e.g. undercut, overlap, surface porosity, incompletely filled groove etc..
3. Visual check for arc strikes.
4. Check weld contour and weld width.
5. Ensure joint is covered with heat resistant material to retard cooling rate (where applicable).
6. Inspect/monitor post-heat treatment (where applicable).
7. Report on weld.
8. Check NDT reports—tie up with NDT (where applicable).

Equipment used for welding inspection

The equipment a welding inspector will need to carry out inspection will depend partly on the work which is to be performed. For example, a welding inspector will not require a fillet weld gauge if only butt welds are being made. The client or specification will also determine the equipment to be used, e.g. a *portable arc monitoring unit (PAM unit)* may be used to measure and record amperage and voltage instead of a hand held voltmeter and ammeter. The equipment which may be used by a welding inspector is listed below:

- a. Steel rule.
- b. Flexible tape measure.
- c. Temperature indicating crayons or thermocouple (pyrometer).
- d. Bevel angle gauges.
- e. Root gap gauges.
- f. Fillet weld gauges for leg length and throat thickness.
- g. Misalignment gauge.
- h. Voltmeter.
- i. Ammeter.
- j. Polarity indicator.
- k. Height/depth gauge.
- l. Contour gauge.
- m. Torch or other light source.
- n. Modelling clay or resin.
- o. Magnifying glass - 5x magnification.
- p. Marking crayon or paint stick.

NOTES

A senior welding inspector may be required to manage and control an inspection contract, to lead a team of welding inspectors who will look to him for guidance, especially on subjects of a technical nature. The SWI will be expected to give advice, handle problems, take decisions and lead from the front. The SWI will therefore require leadership skills in addition to technical skills and experience.

Leadership requirements

Technical skills can normally be taught to the full in the classroom, however, leadership skills may be taught to some extent in the classroom, but are an inherent part of an individual's character and temperament, and therefore must be fine tuned by practical application.

Leadership requirements include:

- a. the willingness and ability to accept orders from senior staff and to act in the manner prescribed;
- b. the willingness and ability to give orders in a clear, concise, verbal or written manner, which will enable the recipient to carry out the action(s) required with full confidence, i.e. leaving no doubt as to what is required;
- c. the willingness to stand up and be counted, not only for a job well done, but also when things go wrong, perhaps due to your direction, or lack of it;
- d. the capability to listen, if and when explanations are necessary for any reason, and to follow up with constructive reasoning and advice;
- e. the willingness to let your staff get on with the job and to trust them to act in a professional manner whilst you stay in the background *managing*;
- f. the ability to back up members of your team, whether technically, administratively or otherwise, as and when required;

Technical skills for an SWI

Knowledge of technology

Welding technology knowledge required for an SWI is similar to that required for a welding inspector but with some additional scope and depth. Additional knowledge is required in the following areas:

- a. Commonly used NDT techniques (a good *appreciation* required).
- b. Radiographic interpretation.
- c. QA/QC knowledge.
- d. Basic metallurgy of commonly welded materials including assessment of fracture surfaces.

e) Basic knowledge of reading drawings.

Knowledge of normative documents

Except when taking examinations, welding inspectors of any level would not be expected to memorise the content of normative documents (specifications, codes of practice etc.) in use. At the workplace the specified normative documents should all be available; the SWI would be expected to read, understand and apply them with the necessary level of precision and direction required.

The SWI should be aware of common *standards* applied in the welding industry, these include:

- a. Standards for welding procedure approval:
BS EN 288, ASME IX.
- b. Standards for welder approval:
BS EN 287, BS 4872, ASME IX.
- c. Standards for quality of fabrication:
BS 2633, BS 5500, AWS D1.1, ASME VIII.

NOTES

- d. Standards for consumables:
BS 639, BS 2901, BS 4165, AWS A5.1.

Knowledge of planning

Planning will be required for all phases of a contract from inception to completion. Planning for inspection would usually relate to the following areas as a minimum:

- Pre-contract—job requirements; allocation of correct staff; collection of codes, drawings and other technical data; general administrative arrangements; work schedule.
- In-contract—application of actual inspection and production of documentation, e.g. equipment required, personnel approvals (welding/NDT etc.), procedure approvals (weld/NDT etc.); inspection and testing of components.
- Post-contract—compilation of all test data, inspection reports and certification.

There are various ways for dealing with the planning function for inspection; methods include:

- a. Place an inspector permanently at the work place and expect him to use his time in a useful and expedient manner.
- b. Use charts which define job function(s) and estimated work time. This may reduce the actual *inspection hours* required but requires greater mobility and more effort from the inspector.
- c. Make a detailed assessment of the overall production plan. This may be done by the use of *forward scheduling* (network planning) which may take the form of *critical path analysis* (CPA), or *programme evaluation review technique* (PERT). Both techniques use the same principal of defining the sequence of operations by means of a network of links or arrows. Alternatively a technique known as *reverse scheduling* may be used in which the completion date for the last operation is determined and then all other operations are worked back from it each with their own target date.

Knowledge of organisation

Organisational skills are necessary to ensure that the inspection requirements of any plan can be met on time using the correct personnel for the job. This may require individuals being assessed for technical, physical and mental abilities to ensure that they are able to perform the tasks required, as well as ensuring their actual availability at the time required and the supervising/monitoring of their actions to completion of the contract.

Knowledge of auditing

The term *audit* basically means to check against documented criteria. Auditing may take place at any phase in a contract:

- a. pre-production, e.g. may assess ability/qualification of staff; staff availability; planned work scheduling.
- b. in-production, e.g. may assess whether specifications are being adhered to.
- c. post-production, e.g. may assess the overall standards of welding and inspection.

The actual audit may involve detailed checks of a very limited area of inspection to ensure that the documentation produced meets the requirements of the specification. Alternatively, an overall check of the inspection function may be made where, for example, the content of a particular file is examined for presentation and content.

The Duties of the Welding Inspector:

My duties as a welding Inspector are involved before, during and after welding.

Before welding:

- all applicable documents are checked;
- application standard is up-to-date with the latest edition, revision or amendment;
- the drawings is clear and issue number is marked;
- welding procedure sheets (specifications) is available and has been approved as required by the authority and is employed in production;
- welder qualifications with identification and range of approval are verified and that only approved welders as required are used in production;
- safety permits such as gas free (entering enclosed space) certificate, hot work permit are available and valid;
- calibration certificates, material certificates (mill sheets) and consumer certificates are available;
- quality plan is authorized and endorsed with signature, date and company stamp;
- parent material identification is verified against documentation and markings;
- material composition, type and condition are checked;
- identification of welding consumables such as electrodes, special drying requirements for electrodes, filler wires, fluxes, shielding and backing gases are verified correct;
- plant and equipment are in safe condition and adequate for job;
- correct methods are applied in cutting and machining;
- dimensions, tolerances, preparation, fit-up and alignment are in accordance with the approved drawings;
- cleanliness is maintained;
- preheating for any tack welding is in accordance with specified procedure;

During welding:

- welding processes such as root pass and tack welds must be monitored and inspected;
- welding should be completed without undue interruption and within specified period;
- hot pass must be timed;
- essential variables such as current, voltage, travel speed and number of runs must be monitored;
- inter pass cleaning, temperature and run sequence should be inspected (roving inspection).
- welding is in compliance with welding procedure sheet and application standard.

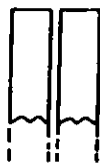
After welding:

- dimensional accuracy must be checked;
- visual inspection is carried out to ascertain acceptability of appearance of welds;
- post welding heat treatment if any should be monitored and recorded;
- NDT report is assessed;
- delayed inspection is carried out 72 hours later to check hydrogen (H_2) cracking;
- factors influencing the formation of weld defects and their acceptability in relation to the written specification are appreciated;
- if repairs are required then
 - ❖ procedures and welder codes should be authorized;
 - ❖ defect area should be marked out positively and clearly;
 - ❖ partial and fully removal should be monitored with visual inspections and NDT;
 - ❖ re-welding should be monitored and re-inspected (visual and NDT).

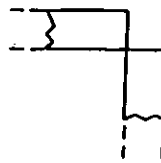
Collate all documents and reports, pass on for final inspection, approval and storage.

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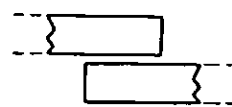
Types of joint



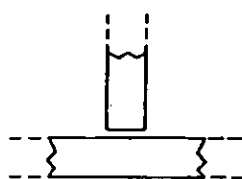
Edge



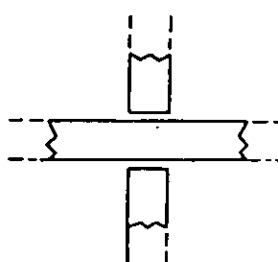
Corner



Lap



Tee

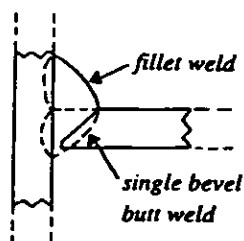


Cruciform



Butt

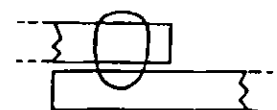
Types of weld



Compound



Fillet



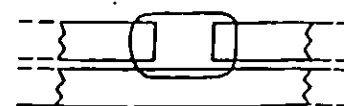
Spot (Fusion)



Butt



Edge



Plug

Senior Welding Inspector

General Theory (Situations) - QP-S1

1. You are an SWI who has taken over from an SWI who has been on site for a few months. It becomes obvious that there is a complete lack of morale amongst your inspectors but they do not approach you to discuss any grievance. What would be your approach to the situation?
2. You are an SWI responsible for a team of welding inspectors who have been on-site for two months. A welding inspector who has been on site for only one week informs you that the contractor has approached him with an offer of money in return for "turning a blind eye" when certain welding work is being performed. Discuss your possible course of action.
3. You are the SWI working on behalf of a client on project to build an offshore platform. You discover that one of the welding inspectors, supplied from a different agency, who has been on the site for one week, does not hold a valid welding inspector approval. State the actions that you would take.
4. You are the SWI on a pipeline project. The radiographic interpreter informs you that he believes that the same weld has been radiographed with different weld numbers on a number of occasions and the radiographs have been submitted. What action do you take?
5. You are the SWI who is required to visit a factory where a number of pressure vessels have just been manufactured and inspected by your inspection team. The client requires the vessels to be *signed off* by you. What questions do you ask, what information do you require and what random checks (if any) do you make before signing off?
6. You visit a fabrication company as an SWI on behalf of a client and you discover in a welder's electrode quiver a number of incorrect electrodes among the correct ones which are very different to those specified for the item being welded. The welder states that he only uses the correct electrodes. State your course of action.

For
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of req. vi.

GUIDANCE FOR SITUATION QUESTIONS (SWI)

1. The low morale but absence of grievances could arise from:
 - a. no real grievances,
 - b. fear of approach to SWI because of personality etc.,
 - c. fear of losing job.

Suggested approach:

Hold meeting to review recent activities.

Identify significant problems.

Seek suggestions to tackle problems.

Assign inspectors to tackle problems.

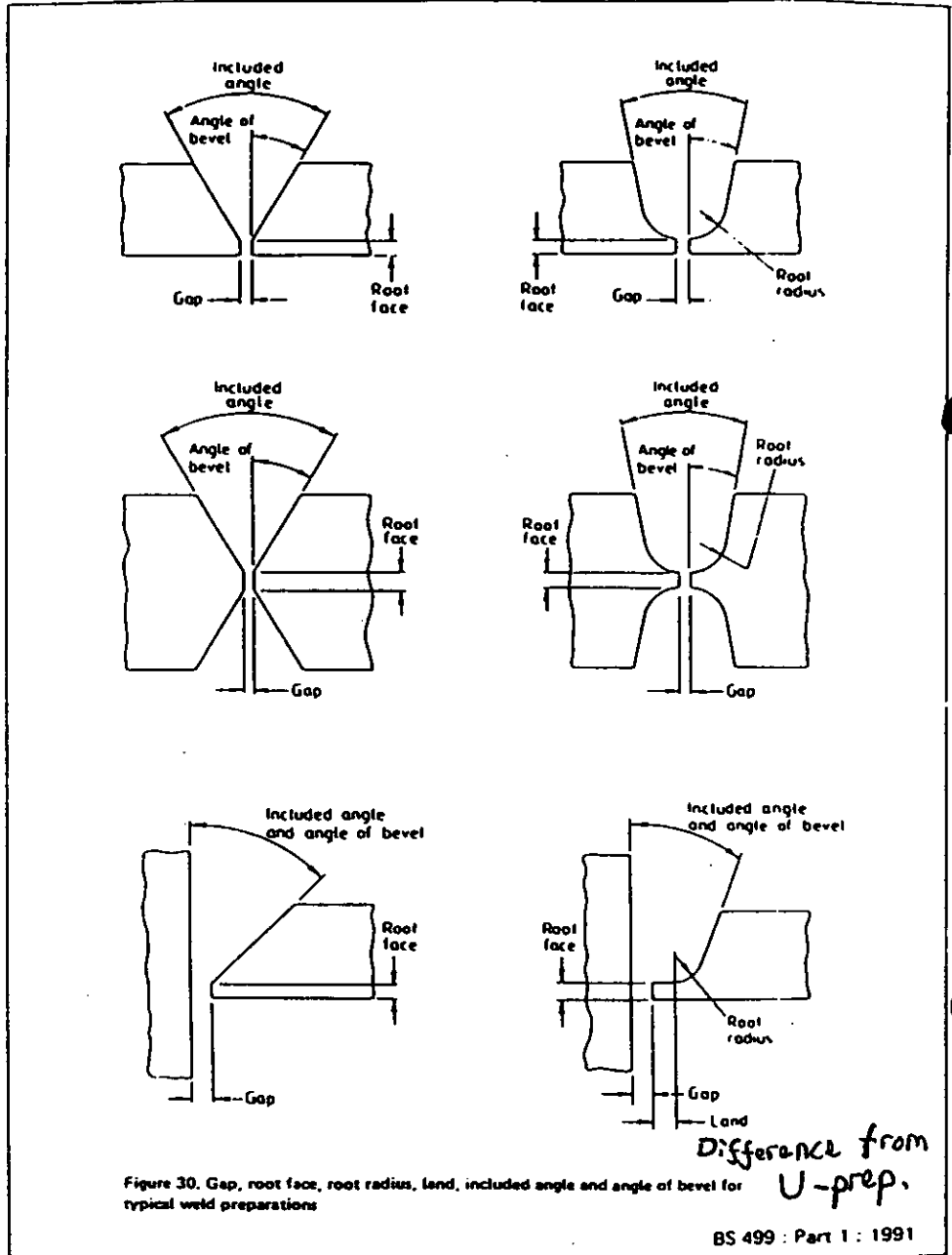
Hold follow-up meetings.

Show enthusiasm.

2. This problem has serious legal implications and it must be approached cautiously.
Ask the inspector for a brief written report of the approach.
Identify the items that might be involved.
Inform SWI's supervisor and hold meeting of supervisor, inspector and SWI.
Assign yourself to the items in question and be especially vigilant for defective work.
Transfer inspector to other work on project.
3. Remove inspector, notify agency and suggest re-certification of inspector.
Notify your supervisor.
Identify all work approved by non-valid inspector.
Stop further work on those items and repeat certification procedures with valid inspector.
4. Recall all radiographs and certificates.
Notify supervisor.
Have independent interpretation made of all radiographs.
If radiographs have been duplicated, identify source of duplication and take disciplinary action.
Repeat all required radiographs.
5. Request welding engineer to check suitability of steels, welds etc. against client specification.
Use checklist for SWI actions.
Check random vessel to ensure complete compliance of certification with client specification.
6. Stop all welding work and check for other incorrect electrodes.
Investigate the procedures for issue of electrodes.
If procedure is inadequate, stop all welding and notify client.
If procedure is adequate, identify all welds made by the welder in question.
Ask for replacement of that welder.
Consult welding engineer to determine corrective action.
Replace all welds made by that welder.

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Types of joint preparation



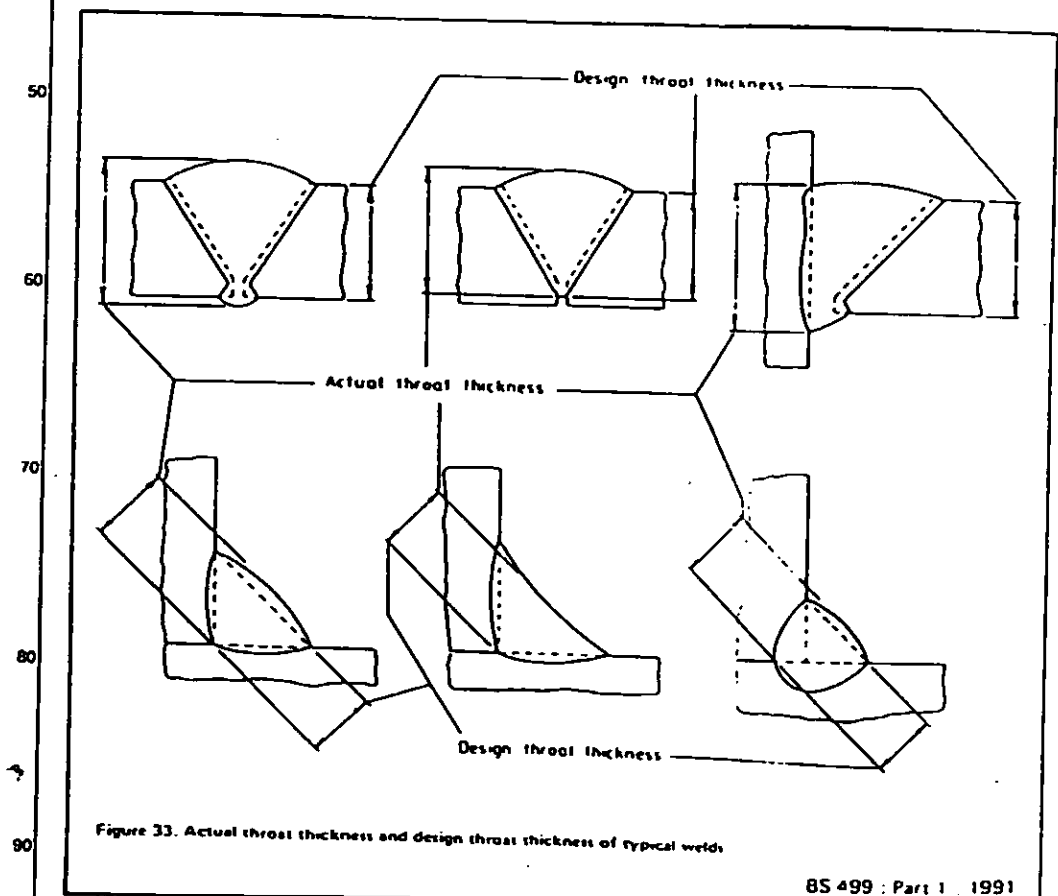
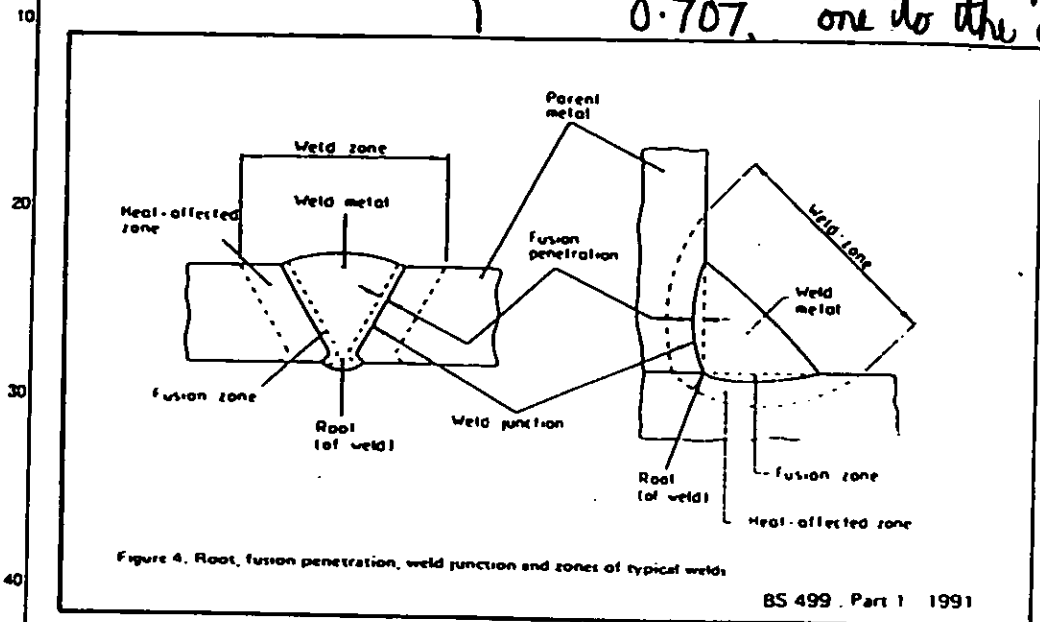
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Weld zone terms

Leg to Throat
1.414 → 1
or 0.707

to convert from
one to the other

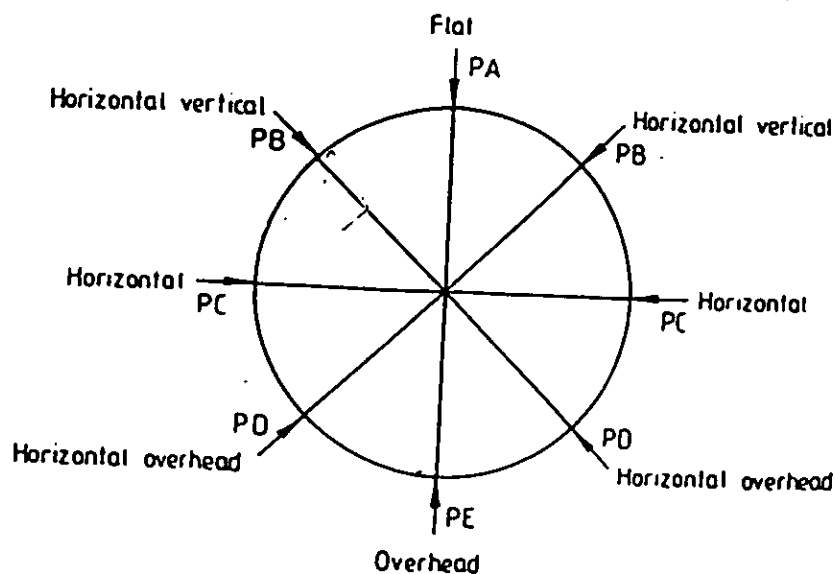


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Weld positions

The following terms and their definitions are in accordance with BS 499 : Part 1 : 1991:

1. **Weld slope:** In the case of straight welds, the angle between the root line and the positive x-axis of the horizontal reference plane. The slope is measured in mathematically positive, i.e. counterclockwise direction.
2. **Weld rotation:** The angle between the centreline of the weld (i.e. the line joining the centres of the weld root at the capping layer) and the positive z axis or a line parallel to the y axis, measured in the mathematically positive (i.e. counter-clockwise) direction in the plane of the transverse cross section of the weld in question.
3. **Welding position:** The orientation of a weld expressed in terms of working position, weld slope and weld rotation.
4. **Flat position:** A welding position in which the welding is horizontal with the centreline of the weld vertical.
5. **Horizontal vertical position:** A welding position in which the welding is horizontal.
6. **Horizontal position:** A welding position in which the welding is horizontal with the centreline of the weld horizontal.
7. **Horizontal overhead position:** A welding position in which the welding is horizontal and overhead.
8. **Overhead position:** A welding position in which the welding is horizontal and overhead with the centreline of the weld vertical.
9. **Vertical up position:** A welding position in which the welding is upwards.
10. **Vertical down position:** A welding position in which the welding is downwards.
11. **Inclined position:** Any welding position not defined by the above positions. The inclined position is defined by slope and rotation.



UNIT W2 • WELD TERMINOLOGY

NOTES

Table 1. Terms and symbols for main welding positions*

Terms	Symbol	Weld slope <i>S</i>	Weld rotation <i>R</i>
31 063 Flat position	PA	0° 180°	90° 90°
31 064 Horizontal vertical position	PB	0° 0° 180° 180°	45° 135° 45° 135°
31 065 Horizontal position	PC	0° 0° 180° 180°	0° 180° 0° 180°
31 066 Horizontal over- head position	PD	0° 0° 180° 180°	225° 315° 225° 315°
31 067 Overhead position	PE	0° 180°	270° 270°
31 068 Vertical up position	PF	90°	—
31 069 Vertical down position	PG	270°	—

*In accordance with ISO 6947.

NOTE 1. To avoid confusion with existing abbreviations, e.g. F for flat, in principle the letter 'P' (for position) has been placed in front of the symbol to indicate 'main position'.

NOTE 2. Tolerances for the main positions are not specified in this British Standard because they depend on the different welding procedures used.

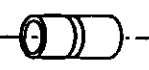
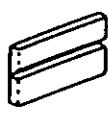
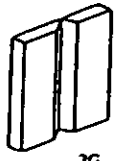
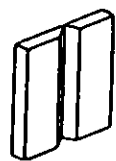
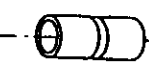
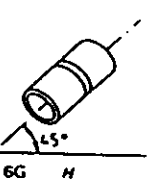
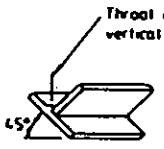
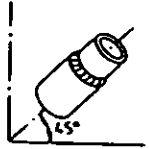
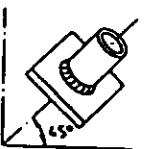
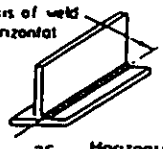
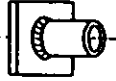
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UNIT W2 • WELD TERMINOLOGY

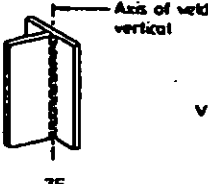
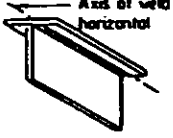
NOTES

Learn

(BS EN 287)

		UK (USA)	ISO
10	 1G rotated  Flat position 1G	1G	PA
20	 2G  Horizontal vertical position 2G	2G	PC
30	 3G PF  Vertical position 3G PG	3G	PF Vertical up PG Vertical down
40	 4G Overhead position	4G	PE
50	 Pipe fixed horizontal axis 5G Vertical position	5G	PF Vertical up PG Vertical down
60	 6G 45° H Inclined position fixed	6G	M-L045
70	 Throat of weld vertical 1F 45°  Flat position 1F  1F (rotated) 45°	1F 1FR	L 45/PA L 45/PA
80	 Axis of weld horizontal 2F  Horizontal vertical position 2F  2F	2F	PB
90	 Pipe horizontal axis 2FR Rotated for weld  2FR (rotated) Horizontal vertical	2FR	PB

NOTES

		UK (USA)	ISO
10	 Axis of weld vertical Vertical position 3F	3F	PF Vertical up PG Vertical down
20	 Axis of weld horizontal 4F Overhead position	4F	PD
30	 4F (Fixed) Pipe fixed axis horizontal Weld: Vertical	SF	PF Vertical up PG Vertical down
40	Figure 38 (concluded)		

NOTES

General

Welding is the process of joining two or more pieces of material together by bringing the atoms of each piece into such close contact that an atomic bond takes place, i.e. the separate pieces fuse together to form one.

This process is not restricted to metals, many materials such as plastic and glass can also be welded.

The first welding carried out was called *forge welding*. As the name implies, it was used in the *forge* or *smithy* by blacksmiths. The method involves heating the pieces of iron to be joined to red heat and hammering them together. Because no melting of the materials is involved, the process is termed *hot solid phase welding* or *welding with pressure*.

Fusion welding is the alternative process to welding with pressure.

Welding with pressure is used to obtain a welded joint between two materials without melting them. The process involves the use of high pressures to bring the materials into close enough contact for an atomic bond to be obtained.

To achieve an atomic bond, the pressure applied must cause plastic deformation of the surfaces being welded in order to break up and remove the oxides on the surfaces. The weld is obtained by atomic diffusion followed by crystal growth across the surfaces being joined.

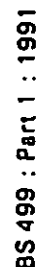
The application of heat, or the generation of heat due to frictional effects, has the effect of reducing the amount of plastic deformation required to produce a bond.

Welding with pressure has a low heat input when compared to fusion welding, this is advantageous for many welding applications. Welding with pressure can also join together dissimilar metals which are difficult to weld with any fusion welding process. However, fusion welding processes are more widely used than the welding processes involved with pressure.

The fusion process relies on the properties of molten materials to easily form atomic bonds. When a material melts, the lattice structures which form the material are destroyed, allowing the atoms to easily mix together. Upon cooling and solidification, the atoms re-form into new lattice structures. These structures may well be different to the original lattice for various reasons, including the rate of heating, the temperatures reached, the rate of cooling, and any additions made to the molten material. Therefore the finished weld may have properties quite different from the parent materials.

Fusion welding processes require a local application of heat in order to bring the material to a temperature at which it will fuse, for steels this is approximately 1400°C to 1500°C. The temperature in the molten weld pool may be in the 2500°C to 3000°C range. The average temperature in the arc is 6000°C. This heat energy is dissipated into the surrounding atmosphere and parent material on either side of the weld.

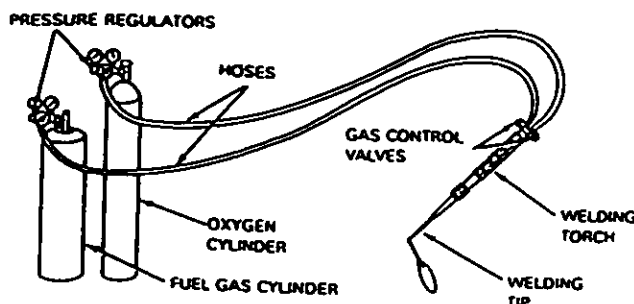
Additions to the weld may be made unintentionally by exposing the molten material to the atmosphere. The gases which form the air (primarily nitrogen and oxygen) are readily combined with the molten metal and undesirable nitrides and oxides may be formed. It is therefore desirable to shield the molten weld metal from the air; most fusion welding processes incorporate a system to protect the weld pool from atmospheric contamination.



NOTES

Oxy-gas welding

The term *oxy-gas welding* is a generic term for a fusion welding process which uses a fuel gas and oxygen to provide a flame hot enough to weld the materials to be joined.



Acetylene is the only fuel gas, when mixed with oxygen, which gives sufficient thermal energy for the commercial welding of steels; a flame temperature of 3100°C is produced. *Oxy-acetylene welding* is suitable for the welding of most metals including carbon steels, stainless steels, cast iron, bronze, copper, aluminium etc.. For all materials except the carbon steels the use of a flux is required.

The main area of application for oxy-gas welding is on metals less than 5 mm thickness, although thicker sections may be welded.

The main disadvantage of oxy-gas welding is the slow speed of travel (and therefore heat input), this causes a wide h.a.z., possibly undesirable metallurgical changes and distortion.

In recent years the process has declined in popularity, mainly due to the development of other more efficient processes such as t.i.g., m.i.g./m.a.g. and plasma arc.

Process technique

The high temperature flame is used to bring a small area of the parent metal up to melting point, a separate filler wire is then dipped into the molten pool and a portion melted off, this mixes with the base metal to provide the weld.

Two main welding techniques are used for oxy-gas welding:

Forehand technique

The filler wire precedes the blowpipe along the seam to be welded. The forehand technique is for general purpose work.

Backhand technique

The backhand technique is vice versa to the forehand technique, i.e. the blowpipe precedes the filler wire along the welded joint. This technique can be used on thicker sections and, with modifications, on positional work.

The oxy-acetylene flame

There are three distinct flame types which can be set with oxy-acetylene and these are as follows:

The neutral flame

The neutral flame is combined from equal quantities of oxygen and acetylene and has a distinct inner white cone with a rounded tip. This flame is the most frequently used. It is suitable for all carbon steels, cast irons, low alloy steels and aluminium.

NOTES

The carburizing (carbonizing) flame

The carburizing flame has a slight excess of acetylene and is identified by the feather around the inner white cone. The flame is suitable for the welding of high carbon steels and for hard surfacing applications. Some welders prefer a very slightly carburising flame when welding aluminium as it ensures that there is no chance of excess oxygen being present to contaminate the weld pool.

The oxidizing flame

The oxidizing flame has an excess of oxygen and is identified by an inner white cone which is shorter and sharper than the neutral cone. This flame is suitable for all brass, bronze, zinc applications, i.e. bronze welding and brazing.

OXIDIZING

Sharp inner cone,
deeper colour
in centre



NEUTRAL

Fully luminous
inner cone



CARBURIZING

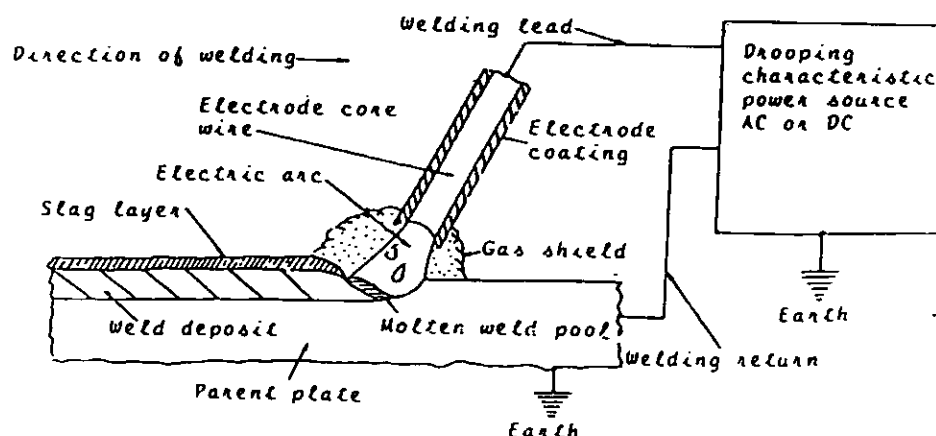
Feather of excess
acetylene around
inner cone



Manual metal-arc (m.m.a.) welding

Manual metal arc welding is the most versatile of the welding processes, suitable for almost all thicknesses and types of ferrous and most non-ferrous metals. Welding can be carried out in all positions relatively economically with reasonable ease of use, although the eventual weld quality is dependent mainly upon the skill of the welder.

Manual metal arc welding is an arc welding process, the heat being provided by an electric arc which is itself formed between a flux coated consumable electrode and the metal being welded. The arc has an average temperature of around 6,000°C which is more than sufficient to melt the parent metal, consumable electrode and flux.



NOTES

Pg 1 Note 2 1

Large arc
Length = more
volts.

Power requirements

M.m.a. welding is carried out using either a.c. or d.c.. In the case of d.c., positive (+ve) or negative (-ve) polarity may be used. The actual current form selected is dependent upon the composition of the electrode flux coating and the specified requirements of the weld. A.c. transformers are the most cost effective form of power source.

Power for m.m.a. can be obtained from either transformers, transformer-rectifiers, generators or inverters. Note 2.

Regardless of type, the welding plant must provide the following:

- a high open circuit voltage (o.c.v.) to initiate the arc, e.g. 65-90 volts, and a lower arc or welding voltage to maintain the arc, e.g. 20-40 volts; therefore the plant must have a *drooping characteristic*. See Unit W11.
- a reasonable range of current must be available: 30-350 amps is typical. Approximately 500 amps would be the maximum capable of being handled manually.
- arc stability. A rapid arc reignition (arc recovery) must be available after short circuiting without excessive current surges which can cause spatter.
- a current which remains almost constant even if, as is usual, the operator varies the arc length during welding, so that consistent electrode burn off rate and weld penetration characteristics are maintained.

Current (amperage)

The welding current, measured in amperes, controls electrode burn off rate and depth of penetration. The possible effects of having an incorrect amperage when using m.m.a. are shown below:

Amperage too low	Poor penetration or fusion, unstable arc, irregular bead shape, slag inclusions, porosity, electrode freezes to the weld, possible stray arc-strikes.
Amperage too high	Excessive penetration, burn throughs, porosity, spatter, deep craters, undercut, electrode overheats, high deposition (positional welding difficult).

Voltage

The welding potential (voltage) controls the weld pool fluidity. The possible effects of having an incorrect voltage when using m.m.a. are shown below:

Voltage too low	only small effect. Poor penetration, electrode freezes to work, possible stray arcs, fusion defects, slag inclusions, unstable arc, irregular bead shape.
Voltage too high	Porosity, spatter, arc wander, irregular bead, slag inclusions, very fluid weld pool, positional welding difficult. (vertical up)

NOTES

Speed of travel

The speed of travel affects heat input and therefore also affects metallurgical and mechanical conditions. The possible effects of having an incorrect welding speed when using m.m.a. are shown below:

Note 1.	Travel speed too fast	Narrow thin bead, slag inclusions, fast cooling, (metallurgical problems?), undercut, poor fusion/penetration.
	Travel speed too slow	Excessive deposition, cold laps, slag inclusions, irregular bead shape.

Current type

The current type, and more specifically its polarity, determines the heat distribution at the arc.

D.c. electrode positive

An electrode connected to the d.c. +ve pole will have two thirds of the available energy—which is mainly heat—developing in the electrode tip with the remaining one third of the energy in the parent material.

This connection produces a wide, shallow weld pool with a broad h.a.z., which together slow down the rate of cooling and reduce the possibility of hydrogen entrapment and/or the development of a brittle metallurgical structure.

D.c. electrode negative

An electrode connected to the d.c. -ve pole has reversed energy distribution compared to d.c. +ve and therefore has one third of the energy develops at the electrode and two thirds of the energy in the parent material.

This creates a rapid development of the weld pool which is narrow, deep and fast freezing with a limited h.a.z.. Using this polarity with certain electrodes, may lead to hydrogen entrapment and a brittle metallurgical structure which is more susceptible to cracking during contraction or when external stresses are applied.

A.c.

In an a.c. arc the polarity is reversing 100 times per second (50 c.p.s.). This has the effect of equalising the heat distribution; half the heat at the electrode and half in the parent material.

The weld zone and mechanical characteristics are therefore midway between those produced with electrode d.c. +ve and electrode d.c. -ve.

Consumable electrodes

Three electrode types/coverings are commonly used:

- rutile,
- cellulose,
- basic.

See Unit W10 for further details on consumable electrodes for m.m.a. welding.

Note 2

width

NOTES

Not 1.

There are m.i.g./m.a.g. processes which use a flux, either in the core of the wire or as a coating on the wire.

If a gas is inert it will not produce any reaction with another chemical.

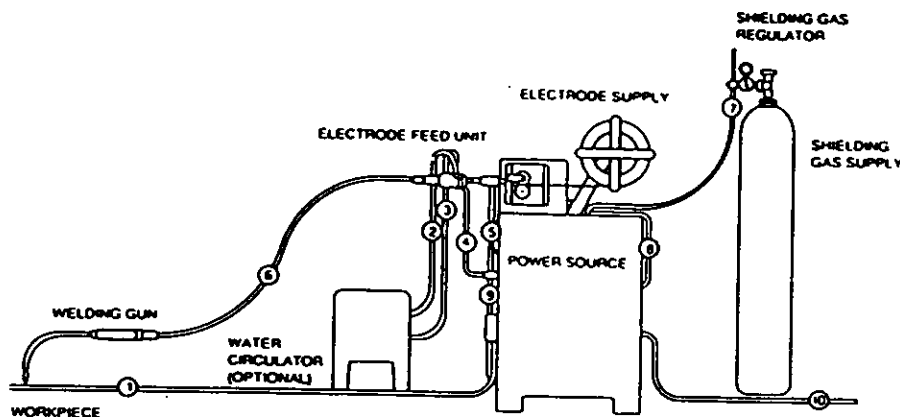
If a gas is active it is capable of reacting with another chemical, e.g. CO_2 is an active gas and it will react with iron, especially at high temperatures, to produce iron oxide.

Metal inert-gas and metal active-gas welding

Metal inert-gas (M.i.g.) and metal active-gas (m.a.g.) welding may be considered together because the welding equipment, including power source, is essentially the same. It is the shielding gas and consumables (filler wires) which differ.

The m.i.g./m.a.g. welding process uses a bare wire consumable electrode to provide the arc and weld metal. The wire, typically 0.8-1.6 mm diameter, is continuously fed from a coil through a specially designed welding gun.

Because the process is fluxless, it is necessary to eliminate the possibility of atmospheric contamination by introducing a shielding gas. For some materials, argon is an efficient shielding gas, being inert, it does not chemically react with the weld metal. When an inert gas is used for shielding the welding process is known as *metal inert-gas (m.i.g.) welding*.

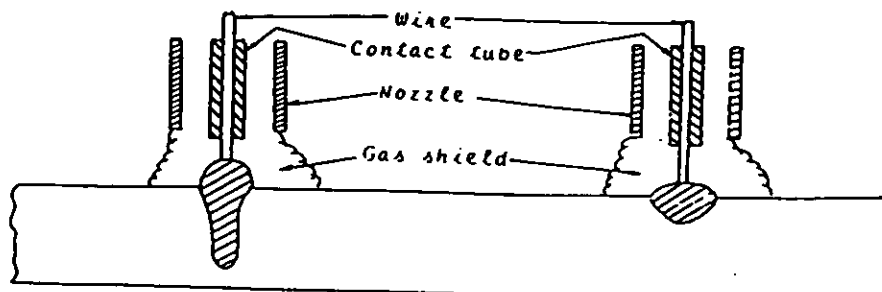


- ① WORK LEAD
- ② WATER TO GUN
- ③ WATER FROM GUN
- ④ GUN SWITCH CIRCUIT
- ⑤ SHIELDING GAS TO GUN

- ⑥ CABLE ASSEMBLY
- ⑦ SHIELDING GAS FROM CYLINDER
- ⑧ WELDING CONTACTOR CONTROL
- ⑨ POWER CABLE
- ⑩ PRIMARY INPUT POWER

Different shielding gases change the electrical properties of the arc, this influences metal transfer properties, heat input, penetration and weld profile characteristics.

The shielding gas selected will depend on the material to be welded, the corresponding filler wire, and the required characteristics of the weld. For example, carbon steel—as an electrode—cannot be transferred successfully through a pure argon shielded arc; a very irregular weld profile with poor fusion would result.



100% CO_2 , deep, narrow weld bead, high profile.

75% Ar + 25% CO_2 , wide, shallow weld bead, flatter profile.

NOTES

Silicon is a primary deoxidizer; manganese is a secondary deoxidizer. A tertiary deoxidizer used in triple deoxidized wire is aluminium.

Carbon steel can be transferred successfully through an arc using carbon dioxide (CO_2) as the shielding gas. CO_2 is an active gas, i.e. it chemically reacts with the weld pool to produce an oxide, therefore extra deoxidizers must exist in the wire for an acceptable weld to be produced. This process is widely referred to as CO_2 welding but is also called *metal active-gas (m.a.g.) welding*. This latter terminology also applies to the process when other active gases/gas mixtures are used, e.g. 75% argon, 25% CO_2 .

Shielding gases

The gas shield fulfils two main functions:

- it provides a suitable ionizable atmosphere for the electric arc,
- it protects the weld pool from atmospheric contamination.

Example gases and applications for m.i.g./m.a.g. welding

Gas	Application examples
Pure argon	Aluminium, copper, 9% nickel steel
Argon + 1% to 5% oxygen	Stainless steel
CO_2 (carbon dioxide)	C steel up to 0.4% C, low alloy steel
Argon + 5% to 25% CO_2	Carbon and low alloy steels
Argon + 5% hydrogen	Nickel and its alloys
Argon + 15% nitrogen	Copper and its alloys
75% helium + 25% argon	Aluminium and copper
75% helium + 25% argon + CO_2 trace	Austenitic stainless steel
Note: A H_2 trace may be added to most gases to increase arc voltage and therefore overall deposition rates.	

Wire consumable

Tig also

now is BS EN 441

The solid wire consumable used for m.i.g./m.a.g. welding should conform to BS 2901 Part 1 - Filler rods and wires for gas-shielded arc welding or other agreed specification.

Because of the porosity problems which can occur when welding carbon steels with the m.a.g. process, fully deoxidized (killed) wire, such as silicon manganese, should be used.

A17 & A18 wire

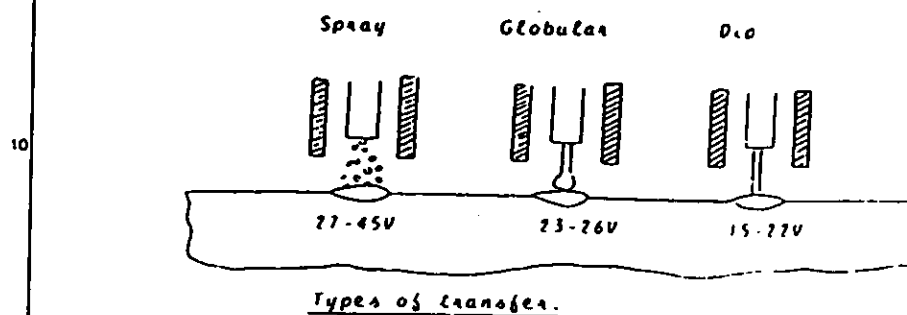
Triple de-oxidised:- A15,

Metal transfer modes

Metal transfer for m.i.g./m.a.g. welding may be achieved in one of four ways:

- spray or free flight transfer,
- dip transfer (semi-short circuiting arc),
- globular transfer,
- pulsed transfer.

NOTES

**Spray or free flight transfer**

If a high welding current is used, the weld metal transfers across the arc in the form of a fine spray. This type of transfer gives high deposition rates and deep penetration welds. The spray transfer mode is suited to thick materials, and except for the light alloys may only be used in the flat or horizontal welding positions.

Dip transfer (semi-short circuiting arc)

To achieve dip transfer mode both low amperage and low arc volts are required so that the consumable wire electrode touches the weld pool and short circuits. This is followed by a short, rapid rise in current which causes the tip of the wire to melt off creating an arc which gradually reduces in length until it short circuits again and the process is repeated.

Because this transfer mode produces a relatively cool arc, it can be used on thinner sections and for all positional welding, including vertical down welding.

Globular transfer

Globular transfer mode occurs in the intermediate range between spray and dip transfer. This transfer mode has no manual application area in m.i.g./m.a.g. welding and only limited success on mechanized and automatic set-ups.

Pulsed transfer

Pulsed arc is a modified form of spray transfer which effectively uses both the dip and spray transfer modes in one operation.

Pulses of high powered spray transfer current are superimposed over a constant low semi-short circuiting background mode. This results in a lower heat output compared to true spray transfer but is greater than with dip transfer; this permits *hotter* welding which allows for high deposition rates and all positional welding.

The main advantage of the pulsed transfer mode is that poor fusion of root runs is virtually eliminated. There is also regular penetration, no spatter, good profile, and the welds are of high quality.

Power requirements

Power for m.i.g./m.a.g. welding is usually electrode d.c. +ve of a flat (constant voltage) characteristic, this can be obtained from a generator or transformer-rectifier. See Unit W11.

NOTES

Advantages and disadvantages

The advantages and disadvantages of the m.i.g./m.a.g. welding process particularly when compared to m.m.a. welding can be summarized as follows:

Advantages

- minimal wastage of consumable electrode,
- no frequent changing of consumable electrode,
- little or no interpass cleaning required (no slag produced),
- heavier weld beads are produced,
- faster welding process,
- low hydrogen process - preheat may not be required.

Disadvantages

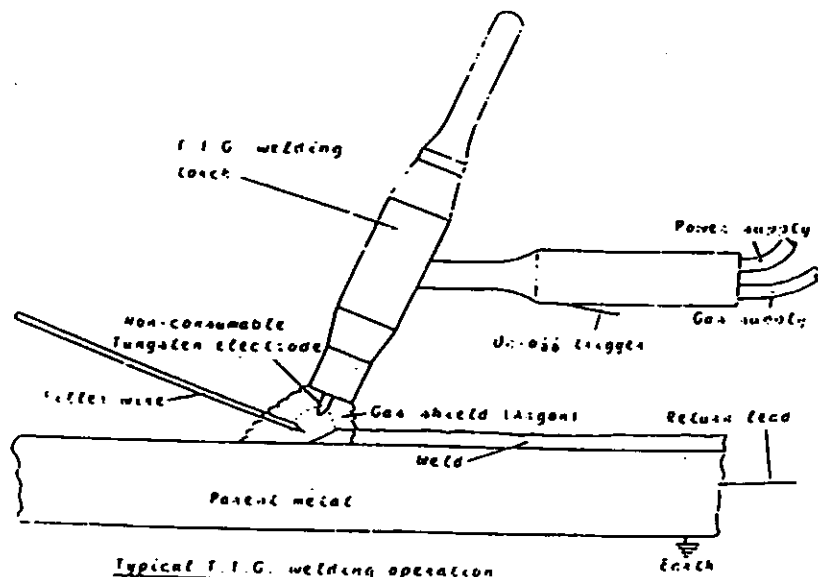
- increased risk of porosity - due to displacement of the gas shield,
- more maintenance of plant involved,
- high risk of lack of fusion. (with dip transfer only)
- Cost of plant, equipment. • Not as flexible.

Tungsten inert gas (t.i.g.) welding

General

The t.i.g. welding process uses a non-consumable tungsten electrode to provide an arc. Filler metal, when required, is fed from a separate filler rod in a manner similar to oxy-acetylene welding. A shielding gas, e.g. argon, is fed through the welding gun to the weld area and provides a gas shield to prevent contamination by the atmospheric gases. No fluxes are used with the process.

When the arc only is used to produce the weld, without the addition of separately fed filler wire, the process is known as autogenous t.i.g.



Although initially developed for the light alloys, i.e. aluminium and magnesium, t.i.g. welding may be used on a large variety of metals.

NOTES

The manual t.i.g. process is expensive when compared to most other manual arc welding techniques and is generally only used on carbon steels when high metallurgical and mechanical properties are required for the weld. An example application is for the deposition of high quality root runs on pipework; the fillers and cap are usually deposited by a more cost effective process such as m.m.a. or m.a.g..

When high quality root runs are to be deposited, a *back purge* is used to prevent *oxidizing (coking)* of the weld metal.

When access to the weld area is difficult, e.g. with deep vee preparations or corner welds, the tungsten electrode stick-out length can be increased providing a gas lens is fitted to *stiffen* the gas shield to prevent turbulence, which would otherwise lead to oxidation of the weld metal.

It is possible to automate the t.i.g. process and many systems are in current use, particularly on pipe where the welding head travels on fixed rings around the joint, the electrode may be stationary or may oscillate from side to side. On root beads it is usual to pulse the current to control the penetration.

Tungsten electrodes

There are two classifications for tungsten electrodes:

1. Plain (unactivated) tungsten

Plain tungsten electrodes tend to laminate in use and can cause tungsten inclusions in the weld. This type of electrode is rarely used and is suitable for lower quality general purpose welds on all metals.

2. Activated tungsten

The addition of either thoria or zirconia to the tungsten gives considerable advantages including increased electron emission for better arc striking, re-ignition and stability, particularly with low current values. There is also a reduction in the possibility of tungsten inclusions in the weld.

1% Thoriated tungsten electrodes: used with electrode d.c. -ve for the welding of all metals except the light alloys (aluminium and magnesium).

2% Thoriated tungsten electrodes: as above, but for applications where lower amperages are used and improved arc stability is required.

Zirconiated tungsten electrodes are specifically used with a.c. for the welding of the light alloys.

Selection of current type

In selecting the type of current to be used for t.i.g. welding, consideration has to be given to the material being welded and the requirements of the arc. Sometimes arc stability is of prime importance, but occasionally the removal of surface oxide, i.e. a cleaning action, takes priority.

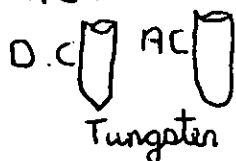
Tungsten has good ionization potential, i.e. electrons and therefore current flow, are easily produced; this produces an inherently stable arc. Electrons flow from negative to positive, therefore natural stability will also be achieved with electrode d.c. -ve. however, because most metals have some natural ionization potential, then stability will also result with electrode d.c. +ve, but the arc voltage will be higher.

When the electrode is negative it is at the cool end of the arc; when it is positive it is at the hot end of the arc.

Tungsten electrodes usually require a clean sharp tip to be maintained during welding. Welding with electrode d.c. +ve can overheat and melt the tip, which becomes globular in shape resulting in an uncontrolled arc and possible tungsten inclusions in the weld metal.

For most metals electrode d.c. -ve is used, the exceptions are aluminium, magnesium, and their alloys.

* 2L of T.i.g. = DC -ve.
u = AC.



Other activators now available include cerium and lanthanum.

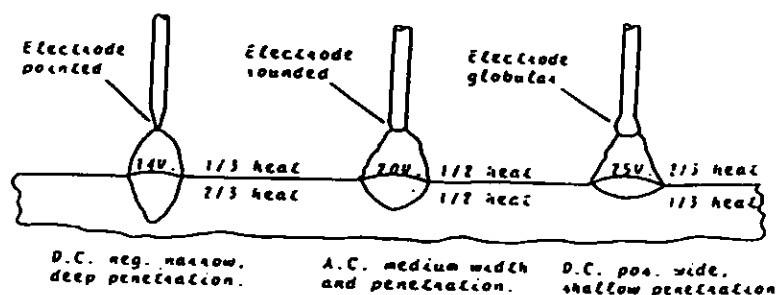
New t. to repli thes
Cerium Oxide - d.c. electrode for steel
Lanthanum
a.c. for light alloys

NOTES

The welding of the light alloys requires an electric arc which is capable of removing the oxide film which has a higher melting point than the material from which it was formed.

There is a scavenging action achieved with electrode d.c. +ve which does not exist with d.c. -ve, therefore from a cleaning point of view, this connection is the one most suitable for the welding of the light alloys. However, electrode d.c. +ve polarity will melt the electrode tip as stated earlier, unless a low current with a very large electrode is used, but this is unsuitable as it creates an unstable arc.

A compromise is met by using alternating current, so that for 50% of each current cycle the electrode is positive, therefore cleaning and welding takes place, and for the other 50% of the time the electrode is negative and is cooled down, therefore melting of the electrode is prevented. In a.c. arcs, because of the reversal of polarity, the heat distribution is even.



Protection of the molten pool

The gas shield fulfils two main functions:

- it provides a suitable ionizable atmosphere for the electric arc.
- it protects the weld pool from atmospheric contamination.

Gas type and gas flow rates are important considerations. Excessive gas pressure can cause *rippling* of the weld pool and give a coarse finish to the weld bead.

Three gases may be considered for t.i.g. welding: argon, helium, and nitrogen.

Argon

The inert gas argon provides a very cost effective gas shield for all metal types. It produces a smooth, quiet arc with low arc volts which makes it ideal for light gauge material or positional welding. It improves the cleaning action when used with a.c. on light alloys.

The addition of between 1% and 5% of the active gas hydrogen will raise the arc voltage and give deeper penetration or increased welding speed on stainless steel, or on carbon steels that can accept the extra hydrogen content in the weld/h.a.z..

Helium

The inert gas helium is lighter than argon, therefore requires higher flow rates (2 to 2.5 times) to give the same effective shielding.

Helium creates a higher arc voltage which is useful for welding thick sections and metals with a high thermal conductivity. When used with a.c. on the light alloys there is less cleaning action when compared to argon. Helium is also more expensive than argon.

Nitrogen

Inert at room temperature, nitrogen combines with oxygen at arc temperatures and becomes active, therefore it is unsuitable for the majority of metals but gives good

NOTES

results on copper as it increases arc voltage which creates more heat and is far more cost effective than argon or helium.

Filler material

The filler material used for t.i.g. welding should conform to BS 2901—*Filler rods and wires for inert gas welding* (or other national/international specifications).

Because of the porosity problems which can occur when welding carbon steels with the t.i.g. process, killed or fully deoxidized wire—such as silicon manganese—should be used. For very high quality welds, triple deoxidized silicon/manganese/aluminium wire is recommended.

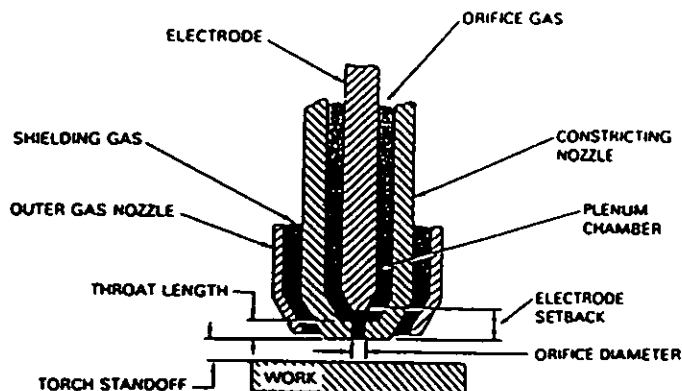
Power source requirements

A high o.c.v. of around 90 volts is required for t.i.g. welding to ensure arc stability at all times. The power source, which may be a generator, transformer or transformer-rectifier must be of a drooping characteristic to maintain a relatively constant current value, the operator being responsible for arc length control. See Unit 15.

To assist arc initiation, to prevent tungsten inclusions in the weld and to prevent damage to the electrode tip, a high voltage, high frequency current is superimposed at the start of all d.c. welding operations. These characteristics are permanent when a.c. is used, to assist arc reignition at the beginning of each positive half cycle.

Plasma arc welding (p.a.w.)

Plasma arc welding is basically a modification of the t.i.g. process, the majority of the equipment being similar, but with modifications to the power source and torch design. P.a.w. can be complementary to, or used as a substitute for, t.i.g. welding, offering greater welding speed, less sensitivity to process variations and consequently better weld quality.



The welding capability range is much greater than t.i.g., particularly for low material thicknesses where *micro-plasma* units can operate as low as 0.1 amps, for the welding of very thin materials.

The p.a.w. process has the ability to perform welds by the *keyhole* technique, this is used on closed square butts on material 1.5-10.0 mm thick. Full penetration in a single pass is achieved with considerably reduced distortion compared to more conventional welding processes.

P.a.w. may require the use of a separately fed filler wire or may be used autogenously.

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Method of operation

The welding torch consists of a non-consumable tungsten electrode set back into a constricted nozzle through which the plasma gas flows, this nozzle lies within another nozzle through which the shielding gas flows.

Gas is fed into the inner nozzle under low pressure and passes through the electric arc where it becomes ionized before being forced through the nozzle constriction. This increases the gas pressure and thus the temperature which is in the range of 10,000-17,000°C. This superheated ionized gas is referred to as *plasma*.

Power source and equipment

A conventional t.i.g. power source, i.e. transformer/rectifier capable of operating in the range from 5 to 200 amps, may be used with an additional *plug in* plasma arc module, although purpose built units are available.

Shielding and plasma gases used are pure argon, helium or argon/helium/hydrogen mixtures dependent upon the material type being welded.

The electrode should be connected to the negative pole when d.c. is being used. When a.c. is used, a *square* wave form is recommended to give instant reversal of current.

Methods of arc transfer

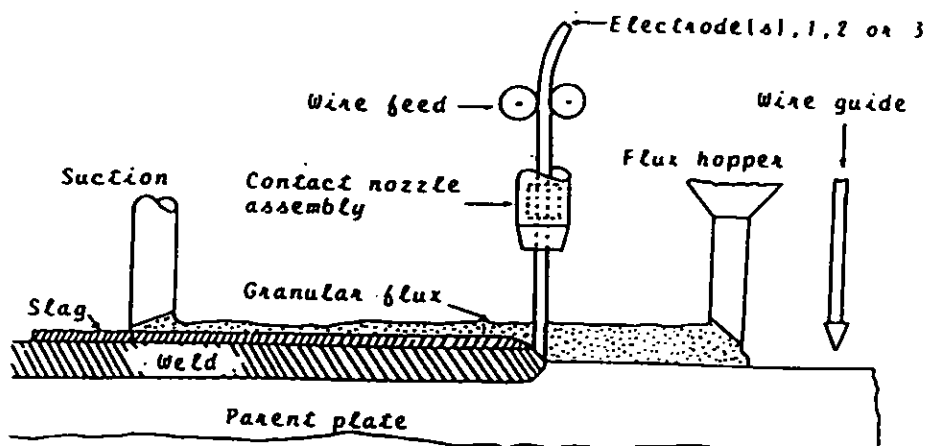
Two means of arc transfer are used in plasma arc welding, these being the *transferred arc* and *non-transferred arc* processes.

With the transferred arc process, the workpiece forms part of the circuit. The arc transfers from the electrode to the workpiece via the plasma gas; this results in additional heat output. The combined temperature of both arc and plasma is in the region of 17,000°C.

With the non-transferred arc process, the arc is initiated between the electrode and the constricting nozzle within the torch and only plasma gas (no arc) exits the nozzle; the work does not form part of the circuit. The plasma temperature is in the range of 10,000°C.

Submerged arc welding

Submerged arc welding uses a continuously fed bare wire consumable electrode, 1.6 to 6.4 mm diameter, to produce a weld pool which is protected from atmospheric contamination by a separately supplied shielding flux in *fused* or *agglomerated* form.



Typical sub-arc welding set up.

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It is possible to feed more than one consumable wire electrode into the weld pool at the same time to increase production rates by up to a factor of five times compared to using a single wire.

Submerged arc welding is normally fully mechanised, but may be used manually or in a fully automatic mode.

The arc and molten weld metal are completely *submerged* beneath the layer of shielding flux and are not visible to the eye. protection against the arc light is therefore unnecessary.

The flux also provides additives to the weld, removes impurities from the weld and provides a thermal blanket (slag) protecting the weld as it cools down. The remaining unused flux is recovered for re-use after the removal of impurities and sieving.

It may be specified that the flux used can only contain a limited amount of recycled flux, e.g. a maximum of 25%. If this is the case the recycled flux must always be thoroughly mixed in with the new flux before use.

An advantage of the submerged arc welding process is that very high welding currents can be used to produce the rapid deposition of heavy weld beads without spatter. Although it is possible to use 5,000 amps or more to produce for example a 37 mm thick weld in one pass, it is more usual to restrict the current to around 1000-2000 amps and deposit a multi-run weld because of the improvement in metallurgical properties.

Power source and equipment

Both a.c. and d.c. power sources are used with s.a.w. with a typical current output of 400-1500 amps. Both drooping characteristic and flat characteristic power sources are used. See also Unit W11. Because of the high current draw off, a 100% duty cycle capability is recommended.

Flat characteristic d.c. power sources are the type most commonly used for applications where the current does not exceed 1000 amps, they are also the best for the high speed welding of thinner steel sections.

Above 1000 amps and for thicker sections, drooping characteristic a.c. is preferred and works best if the sine waves are *square* because polarity reversal is instantaneous. A.c. is also preferable for multi-wire techniques and applications where *arc-blow* is a problem.

Single, twin or triple wire feed systems are commonly used, all feeding into the same weld pool. All the wires may be *live*, or *dead* fillers may be applied. In a multi-wire application, the leading wire is usually d.c. +ve polarity, this will limit the risk of burn through, although deep penetration will be achieved because of the high current used. A.c. would normally be used for the remaining wire(s), or dead fillers could be used, or a combination of both.

Application areas

Submerged arc welding is widely used in ship building, structural steel work, general engineering applications, and for the fabrication of pipes and pipelines, e.g. double jointing stations. Carbon steel, alloy steel and stainless steels are the main materials welded using this process.

Because of the heavy deposition rates and fluid slag, it is only possible to weld in the flat or horizontal vertical position. However, circumferential welds may be made on pipes or vessels. For this application the welding head remains stationary while the workpiece rotates beneath it.

Fluxes and wires to BS 4165

Weld quality and properties are influenced by the choice of wire and flux. The determination of the best wire and flux combination to use to give optimum qualities is often a case of trial and error. The BS 4165-*Electrode wires and fluxes for the*

Arc-blow is a deviation of the arc due to magnetic influences caused during welding.

let charact <1000amps ($\approx 2.4\phi$)
; drooping >1000amps ($>2.4\phi$)

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s.a.w. of carbon steel and medium-tensile steel, gives requirements for the wire and flux, designates a coding system for s.a.w. wires and fluxes, and also offers guidance on choice.

Fluxes

Fluxes for s.a.w. are divided into two types:

- fused - granulated,
- agglomerated - powdered.

Fluxes can be further classified depending on their *basicity* or *acidity*.

Fused fluxes

Fused fluxes are manufactured as follows: the ingredients are mixed and *melted* at a high temperature, the mixture is then poured onto large chill blocks or directed into a stream of water to produce granules which have a hard glassy appearance. The material is then crushed, sieved for size, and packaged.

Advantages of fused fluxes include:

- good chemical mix achieved,
- they do not attract moisture (not hygroscopic) this improves handling, storage, use, and weldability. Any moisture present is easily removed by low temperature drying,
- the easy removal of impurities and fine particles etc. when recycling.

The main disadvantage is the difficulty in adding deoxidants and ferro-alloys. These would be lost during the high temperature manufacture. The maintenance of a controlled flux depth is considered critical.

Agglomerated fluxes

All the flux materials are dry mixed and then bonded with either potassium or sodium silicate, they are then baked at a temperature below the fusion or melting point and therefore remain as a powder which is sieved for size and packaged.

Advantages of agglomerated fluxes include:

- can be colour coded,
- easy addition of deoxidants and ferro-alloys,
- flux depth not so critical.

Disadvantages include:

- tendency for flux to absorb moisture and difficult redrying procedure,
- possibility of molten slag causing porosity,
- difficult re-cycling, i.e. the removal of impurities and sieving.

Flux basicity or classification

A certain amount of oxygen will exist during welding, some will remain in the weld metal either in gaseous form or as oxide inclusions. The oxygen can be controlled by chemical reactions with the molten flux.

Basic oxides tend to be more stable than *acidic* oxides. Generally the higher the basicity of a flux, the less the production/formation of oxygen (porosity) and oxide inclusions, leading to an improvement of weld metal strength.

main reason for
infrequent use

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Poor

Best

Fluxes for s.a.w. may be classified as follows:

- acid—general purpose use and for dirty (rusty) steel
- neutral
- semi-basic
- basic
- high basicity—maximum weld toughness and performance

IMPROVING QUALITY



The name *electroslag* is derived from the fact that the process uses electrically conducting slag.

Electroslag welding (e.s.w.)

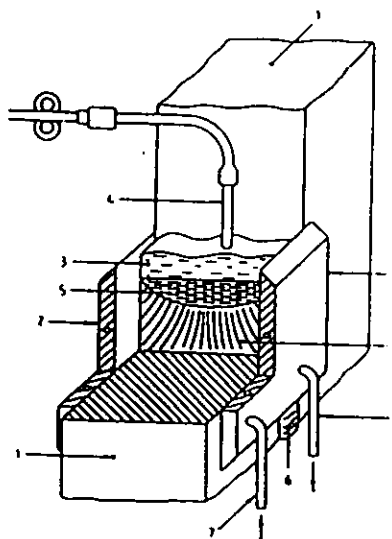
The main application area of the electroslag process is the joining of plates approximately 10 mm thick and above, although plates in excess of 50 mm thick are more likely to be welded using this process. Carbon steel, low alloy steels and austenitic stainless steels are the only materials weldable with the electroslag process.

Welding is carried out only when the plates are in the vertical, or near vertical position. A square cut joint is always used. Once welding has started it must be carried out to completion because restarts produce defective areas. The process is used on ships, pressure vessels, steel castings, structural steel etc..

For welds up to 75 mm thick, the e.s.w. process uses less weld metal and 90% less flux than s.a.w.; plates 75-300 mm thick are welded at 600-1200 mm/hr. Angular distortion is eliminated.

- 1 Plates to be welded
- 2 Shield
- 3 Molten slag
- 4 Electrode
- 5 Molten metal
- 6 Finished weld
- 7 Pipes for cooling medium

Electro-slag welding



BS 499 Part 1 1991

Electroslag welds are relatively defect free, slag entrapment, porosity and lack of fusion defects are almost non-existent. Electroslag welds normally require post-weld heat treatment especially on the thicker materials, due to the resultant coarse grain structure.

A flat characteristic power source is required. A typical 3 mm diameter wire will require 40 volts and 600 amps.

Method of operation

E.s.w. is a fusion welding process which uses the combined effect of current and electrical resistance to produce a conducting bath of molten slag which melts both the filler wire(s) and the surfaces of the workpieces to be welded. The weld pool is also

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shielded by this slag which covers the full surface of the weld and rises as the weld progresses up the joint.

The process is initiated by an arc, usually struck on wire wool type material, which is itself laid onto a *starting block* which supports the initial liquid material.

Powdered flux is placed at the bottom of the joint, this is liquified by the arc which is then extinguished by the now conductive, though highly resistive, molten slag. All the current now passes through this molten slag, the resistance creating heat.

In order to retain the molten mass of flux and weld metal, water cooled copper shoes are fitted either side of the joint and walk or slide progressively upwards as the welding proceeds.

Process options

Two variations of e.s.w. are in general use. These are the *non-consumable guide* and *consumable guide* processes.

Non-consumable guide process

In this technique, one or more wires, depending upon metal thickness, are fed into the molten slag through a guide or guides which are constantly maintained approximately 75 mm above the molten slag. One electrode is required for each 60 mm of metal thickness. If an oscillating or pendulum technique is used this can be increased to 120 mm. This method of e.s.w. is suitable for material thicknesses ranging from 10 to 500 mm thick.

Consumable guide process

With this method, filler metal is supplied by both the electrode and its compatible metal guide. The metal guide directs the wire to the bottom of the joint and extends for the full weld height which may be as much as 10 metres. The guide is *consumed* as welding progresses upwards and can provide from 5 to 15% of the filler metal. One electrode/guide is required for each 60 mm of weld metal but this increases to 150 mm if an oscillating technique is used. The consumable guide technique is suitable for material of unlimited thickness.

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Standard British terminology, as defined in BS 499 : Part 1 : 1991 will be used and related American terminology, as defined in AWS A3.0-89, is shown in italics.

Arc welding processes

Arc processes are the most universally popular methods of welding. It is necessary to recognise:

- a. the important features and capabilities of the various processes,
- b. the type of current required to sustain the arc,
- c. the effects of the arc on the workpiece,
- d. the shielding mechanisms that protect the arc,
- e. the types of consumables and gases used.

The important operating parameters are the current, arc voltage, and travel speed, all of which must usually be controlled within specified limits.

The various arc welding processes will be discussed in two groups because the power sources and other equipment used for each group are broadly similar:

1. Manual metal-arc welding, Tungsten inert gas and plasma welding, in which filler metal is generally added manually.
2. Semi-automatic and automatic processes that run with filler metal deposition from continuous wires: MIG/MAG, Flux-cored wire welding, Submerged arc welding, electroslag, and and electrogas welding.

Manual metal-arc (MMA) welding, *Shielded metal arc welding (SMAW)*

Manual metal arc welding is the most versatile of the welding processes, being suitable for most thicknesses (except for very thin sheet) of ferrous and non-ferrous metals. With suitable electrodes MMA can be used for all welding positions, including vertical-down. Provided suitable precautions are taken to protect the weld from wind and rain, MMA electrodes can be used for site welding.

Electrodes for MMA welding usually consist of a solid metallic core rod, that is coated with a layer of flux, which contains powdered ingredients and a silicate binder. An arc between the end of the core and the workpiece melts the core and the surface of the workpiece. The flux coating is necessary for the following reasons:

- a. protect the arc from the surrounding air,
- b. give good arc stability,
- c. to transfer alloying elements (manganese, silicon, etc.) to the weld metal,
- d. to absorb oxide scale and other impurities,
- e. to produce a slag that will protect and support the weld metal during solidification.

Current passes down the core rod to the arc that melts the end of the rod and the surrounding flux to produce a protective cone. The welding current can be DC+, DC-, or AC, supplied from a drooping characteristic power source that gives essentially constant current output, that can be a rectifier, transformer, or engine-driven generator. Gas, generated from organic material, e.g. cellulose, or limestone in the flux, shields the arc within the cone. In the UK AC is most common whereas in the U.S.A. DC is most popular.

The diameter of the core rod governs the welding current that is used. Low current is indicated by unstable arc, irregular bead shape, excessive slag inclusions, electrode freezes in weld pool. If the current is too high the core rod becomes red hot, the coating starts to smoke and crack, excessive spatter, and porosity increases as the rod burns off. Electrode polarity, depending on the classification, can be DC+ve, DC-ve, or AC. DC+ve gives the deepest penetration, DC-ve gives shallower penetration but

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higher deposition rates at the same current, and AC deposition is preferable where arc blow might be a problem. Inspectors should check that the correct polarity is being used.

Electrodes run at arc voltages that are characteristic of the flux type - higher voltages (about 30 V) for cellulosic pipe welding types, and lower voltages (about 24 V) for basic low-hydrogen types. Normal changes in arc length have a minor effect on arc voltage. For easy starting of the arc, and smooth re-ignition during the half cycles of AC welding, the open circuit voltage (the voltage at zero current) might be as high as 80 V. Increased attention to safety has led to the wider use of power sources with lower open circuit voltages of about 50 OCV. Cellulosic rods will not run with those sets. Some electrodes, especially low-hydrogen types, are made with coated tips to give easy starts by merely touching the tip to the workpiece.

Inspectors should check the electrical code classification for electrodes to ensure that they are compatible with the power source output (open circuit voltage and current type (AC, DC+, DC-)).

MMA positional capability and electrode sizes

Positional capability depends on the flux type and electrode size. MMA electrodes are available with core rod diameters of 1.6, 2.5, 3.25, 4.0, 5.0, and 6.0 mm. Providing that the flux type is suitable, (if it produces a viscous slag) positional capability is indicated in the electrode classification, and positional welding will be possible with electrode core sizes up to 4.00 mm. For vertical-down welding, core sizes can be up to 5.5 mm. Consequently, for general welding purposes, most MMA electrodes are sold in 3.25 and 4.00 mm sizes. Check for suitable positional classification.

Tungsten inert gas, (TIG), *gas tungsten arc welding (GTAW)*

In TIG welding, the arc from a non-consumable tungsten electrode, shielded by an inert gas, usually pure argon, is used to provide heat for melting the workpiece and the filler metal. Tungsten is used as the electrode because its melting point is very high and under the proper welding conditions it will not melt.

If a weld is made by fusing the two closely fitting sides of the joint, without adding filler metal, the weld is called autogenous.

TIG welds are made with drooping characteristic machines, and the arc voltage depends on the inert shielding gas used. Argon gives an arc voltage of about 12 V at normal arc lengths of about one or two millimetres, but if extra arc heat is required for a given current, mixtures of argon-helium gas are used because helium has an arc voltage of about 18 V, giving about 50% more heat for similar current. The extra heat is needed for some nickel alloys, and for heavy sections of aluminium.

TIG welds require carefully controlled current, which can be supplied by sets suitable for MMA, but most TIG welds are made with power sources that have a number of special features. (TIG sets can usually be used for MMA welding.) The welding current can be controlled from the power source, as in MMA welding, but TIG sets usually have the added refinements of hand or foot control of current to obtain precise control of the weld pool.

A TIG arc can be started by several means:

1. Scratching the electrode on the weld surface. This has the disadvantage that tungsten inclusions may enter the weld metal, and the tip may become contaminated with iron or aluminium that will lower its melting point.
2. The most common method is to superimpose a high frequency voltage that will cause a light arc to jump from the electrode when it is held close, but not touching the workpiece.

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3. Some sets have special starting circuits that produce a low current arc when the electrode touches the surface, and the current rises to the welding level when the electrode is withdrawn from the surface.

The filler metal, if added, is fed from a cut length of rod by hand or mechanically in the form of a continuous wire. Unlike MMA, MIG/MAG, and SAW, the amount of filler added is independent of the energy input from the arc. Because current is not flowing through the filler rod, its deposition rate is very slow compared with the those other processes.

TIG welding can be considered to be the arc equivalent of oxy-acetylene welding. It provides very good control of the weld pool and is generally used for precision work with expensive alloys, but because of slow travel speeds its heat input and distortion are higher than from the other arc processes.

TIG welding positional capability and electrode sizes

The precise control of current during TIG arc welding, and the independent addition of filler metal make TIG welding the most popular choice of process for precision all-position welding, such as critical pipe welds. Deposition rates are low, but no other process gives such good quality with minimum repairs.

The size of the tungsten electrode depends on the polarity and current, as shown in the following table, which also includes recommended sizes of gas cups.

Table W3S-1

Recommended maximum current and gas cup size for tungsten electrodes

Diameters, mm		Direct current, amps		Alternating current, amps	
Electrode	Gas cup	DC-ve	DC+ve	Unbalanced wave	Balanced wave
1	10	10-80	.	10-60	20-30
1.6	10	70-150	10-20	50-100	30-60
2.4	12	1500-250	15-30	1000-160	600-130
3.2	12	250-400	25-40	150-210	100-180
4	12	400-500	40-55	200-275	160-240
6.3	20	750-1100	80-125	325-450	325-450

If the currents exceed the values shown, the electrode tips will be melted and eroded, which may cause undesirable loss of tip shape and unacceptable particles may fall into the weld pool. The tungsten electrodes should not melt at the welding current, and the heat generated in the electrode depends on the electrode polarity and its diameter. When the electrode is run at negative polarity, as when welding steels and nickel alloys, the evaporation of electrons from the surface of the tungsten has a cooling effect. As in MIG welding of aluminium alloys, the use of DC+ve polarity has an important cleaning effect because it removes oxides from the metal surface. However, it also reduces the current-carrying capacity of the tungsten electrodes to very low levels, and it gives only shallow penetration. DC-ve polarity gives deeper penetration but it will not give sound welds because of oxide film entrapment.

A satisfactory compromise is reached by using AC, which cleans the metal when the electrode is +ve and gives deeper penetration when it is -ve. The oxide layer acts as a rectifier, resulting in easier current flow when the electrode is -ve. Several modifications of AC welding are available:

1. Continuous high frequency current can be applied to give improved arc ignition during each half +ve cycle.

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2. Square wave AC gives more rapid re-ignition than sine wave AC.
3. The relative currents on each half of the cycle can be adjusted to provide either more cleaning or more penetration.

Classification of tungsten electrodes

TIG welding electrodes can be made from pure tungsten, or tungsten alloyed with small amounts of oxides that improve arc characteristics. The common types are as follows:

- Pure tungsten (colour code: Green) - These are used with a ball end for AC welding of aluminium and magnesium alloys.
- 1% thorium oxide (Yellow), 2% thorium oxide (Red) - These have easier starting characteristics and higher current-carrying capacity. It is easier to maintain a pointed tip which is used for welding steels. Not often used for AC.
- 0.25% zirconium oxide (Brown) - These are the best choice for AC welding, especially for radiographic quality welds in aluminium alloys. They maintain the balled end with good arc stability and best resistance to contamination.
- 2% cerium (Orange) - Ceriated electrodes have been introduced because they have the same benefits as thoriated electrodes but thorium is slightly radioactive.

Filler metals for TIG welding

In general, the filler metals used for TIG welding are similar to those for MIG/MAG welding, and they are classified in the same specifications, such as BS 2901.

Only in rare cases are special grades required for TIG welding. Rimming steels (which contain higher oxygen contents than continuously cast and killed ingot steels) require an addition of aluminium to supplement the manganese and silicon present in MIG/MAG welding wires. In BS 2901: Part 1, this grade is A15 (0.04-0.4% Al), and in AWS A5.2 Grade ER70S-2 contains 0.05-0.15% aluminium plus titanium and zirconium (for improved slag formation) and grade ER70S-5 contains 0.5-0.9% Al.

Shielding gases for TIG welding

Pure argon is the most popular gas used for shielding the tungsten arc. Argon mixtures that are used for MIG/MAG welding of steels should not be used because they contain oxidizing gases that would cause failure of the tungsten.

Helium and argon-helium mixtures are used to raise the arc voltage and produce more heat at a given current, which is useful in welding thick aluminium, and steel sections, and nickel alloys. Helium is lighter than argon and is very expensive, but its use can be justified in some cases.

Argon-hydrogen mixtures can also be used when more heat is required, provided that it does not cause adverse metallurgical effects, such as cracking. The mechanized welding of stainless steels is an example.

Use recommended gas flow rates that depend on the shielding gas used, the welding current, and the diameter of the gas cup.

Plasma arc welding (PAW)

The principles of plasma arc welding are similar to those of TIG welding, but instead of the arc being allowed to develop its normal bell shape from the electrode to the workpiece, the arc, is constricted in the inert gas by a surrounding copper nozzle. The arc gas flows through the nozzle and additional shielding gas flows around it, within an outer shielding gas nozzle. The constricted arc retains a more narrow cylindrical shape which has several benefits:

- a. it gives a higher current density and deeper weld pool penetration,
- b. it gives a longer arc.

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- c. it is much less sensitive to stand-off distance,
- d. it can be run at currents as low as 0.1 A (micro-plasma),
- e. it can be used for keyhole welding.

For metal welding purposes, a transferred plasma arc is used between the tungsten electrode and the workpiece. For relatively few applications the arc is run from the electrode to the nozzle and the gas is heated by flowing through the arc. The arc does not reach the workpiece, and this is known as a non-transferred plasma arc, which is used when a very hot stream of inert gas is required.

Continuous wire welding

Stick electrode welding has an inherent problem. Each stick makes a new weld that requires a start and a finish. The interruptions when discarding the stub and inserting a new electrode result in operating factors that are only about one half of that found in continuous wire welding. Consequently, because of its higher productivity and lower costs, in developed countries, welding with continuous wires has replaced stick electrodes, and in the UK, Germany, USA, etc. continuous wire welding with various processes accounts for well over 50% of all steel weld metal deposited. Continuous wire welding may be semi-automatic or automatic.

Semi-automatic welding is defined in BS 499 : Part 1 : 1991 as "Welding in which some of the welding parameters, such as arc length are automatically controlled, but manual guidance is necessary." (In automatic welding all the parameters are controlled.) Modern semi-automatic welding was made possible by the development of power sources with constant voltage output characteristics, which in combination with a constant speed wire feeder gives rapid arc regulation during the inevitable movement of the gun during manual welding. The term *semi-automatic* is generally applied to the use of continuous electrodes that can be solid or tubular cored wires, and the arc is protected either by a shielding gas (MIG/MAG), a flux (submerged arc or self-shielded FCAW), or both gas and flux (gas-shielded flux-cored arc welding).

Continuous wire welding can be applied to the following processes:

- Metal inert-gas (MIG), metal active-gas (MAG) welding, *gas metal arc welding (GMAW)*.
- Cored wire welding, *flux-cored arc welding (FCAW)*.
- Submerged arc welding (SAW).

Mechanised wire feeding can be applied to TIG and plasma welding in mechanised applications, but those processes generally use cut lengths of filler rod, fed manually into the weld pool.

Power sources, wire feeders, and guns are essentially similar for continuous wire welding, whether they are used for MIG/MAG, FCAW, or SAW, and they are considered as a single group in Unit W11. Powers sources supply the necessary voltage and current, the wire feeder pushes the wire through the cable at controlled speeds, and the gun that must perform three functions:

1. feed the wire into the arc,
2. conduct the welding current to the wire,
3. provide a gas shield around the arc.

MIG/MAG welding

MIG/MAG welding uses a continuous solid wire electrode that is fed into the arc which is protected by a shielding gas, that might be inert or active, depending on the wire being used. No flux is present and all the alloying elements in the weld metal

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must be provided via the wire. The range of different steel compositions available in the form of MIG/MAG wires is very limited compared with MMA electrodes. For steel welds, the wire contains silicon and manganese to combine with oxygen that enters the weld metal from the gas shield, and other alloying elements, such as nickel, chromium, and molybdenum.

MIG/MAG welds are made with the electrode running at positive polarity. In addition to producing deep penetration, this has the added benefit that the flow of electrons from the surface of aluminium and magnesium alloys causes the natural oxide layer to be blasted off the surface, allowing clean high quality welds to be made without the addition of fluxing agents. The cleaned strip alongside a MIG weld in aluminium is quite evident.

DC current with electrode negative polarity and AC is not used for MIG/MAG welding.

It is impossible to deal with the advances now being made in power source technology if we do not understand the way in which metal is transferred across an arc.

Metal transfer when welding with continuous wire electrodes

A clear understanding of metal transfer is very important, especially when dealing with pulsed welding and other sophisticated power sources that are now being introduced. In MIG/MAG welding it is quite obvious that not all welding arcs are the same. Some arcs are very smooth, making a quiet hissing noise, and the molten weld metal is deposited in small well-controlled droplets with very little spatter. Others make a crackling sound and are rougher, throwing the metal from the wire in large drops, some of which miss the pool and spatter the surrounding area. Some arcs have more force than others. Some give deeper penetration and some are very effective in keeping the slag/silicate from running into the arc.

The important types of transfer are globular, short-circuiting (or dip), spray, and pulsed spray. The important factors that control metal transfer are:

- a. current,
- b. voltage,
- c. wire diameter,
- d. electrode extension (stick-out,
- e. shielding gas.

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The conditions that lead to the various types of transfer are shown in the following table:

Table W3-2

Principle factors that influence mode of transfer during MIG/MAG welding

Transfer mode	Shielding gas	Wire diam*, mm	Average current*, A	Voltage
Globular	CO ₂ Ar+>10% CO ₂	0.8	All currents	>22
		1.0		
		1.2		
		1.6		
Axial spray	Ar, Ar-O ₂ Ar+<10% CO ₂	0.8	>160	28-35
		1.0	>180	
		1.2	>230	
		1.6	>275	
Dip transfer	All shielding gases	0.8	<160	16-22
		1.0	<180	
		1.2	<230	
		1.6	<275	
Pulsed spray	Ar, Ar-O ₂ Ar+<10% CO ₂			
* Electrode extension also influences the transition current.				

Whereas the shielding gas and current control the transfer mode with solid wires, the mode of transfer from tubular wires tends to be dominated by the core type. The dominating role of the flux allows transfer type to be used as a means of classifying cored wires. The mode of metal transfer is reasonably easy to recognise and the American Welding Society uses metal transfer as one of the ways to classify wires for specification purposes.

Globular transfer

During globular transfer, the end of the wire melts and forms drops that move around the tip of the wire. This is seen at low currents with all shielding gases, and at higher currents in all gases except argon-rich gases with less than about 10% CO₂. Argon-20%CO₂ and pure CO₂ give globular transfer at high currents. The characteristics of globular transfer are a crackling arc, broad penetration, and moderate spatter, which increases with the CO₂ content of the shielding gas. Argon-20%CO₂ is an economical compromise. Pure CO₂ is cheaper but spatter cleanup costs are higher.

Transition current

In argon-rich gases, such as Ar-10%CO₂, low currents give globular transfer, but if the current is raised the transfer will suddenly change to axial spray transfer at what is known as the transition current. The value of the transition current depends on the wire diameter and the electrode extension, and typical values are shown in Table W3-2 above. There is no transition current in gases with higher CO₂ contents.

Axial spray transfer

In spray transfer from a solid wire, the arc climbs a short distance up the wire which melts to a pointed end. The metal leaves the point in a spray of very small droplets that are cleanly projected in line with the axis of the wire. The momentum of the stream of hot droplets causes deep penetration along the centre line of the weld, which in cross section is known as *finger penetration*. Spray transfer is clean, and produces relatively little fume, but its disadvantage is that it occurs only at relatively high currents with solid wires. Continuous (as opposed to pulsed) high currents produce

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large weld pools which are unsuitable for vertical and overhead welding. Therefore, continuous spray arc transfer from solid wires is used only for flat and horizontal welding of steel or aluminium alloys.

Axial spray transfer is seen clearly with solid steel wires, in argon and argon-based gases that contain up to about 10% oxidizing gas, such as oxygen or carbon dioxide, but only at currents above the transition current. Spray transfer is not seen at any current in other shielding gases, such as argon-based gases containing more than about 10% carbon dioxide, or in pure carbon dioxide.

Spray transfer is seen with a number of types of cored wires, although the axial spray is not as concentrated as it is with solid wires. Consequently, a spray arc weld pool produced by an EXXT-1 wire has deep penetration but it does not show the narrow finger penetration typical of solid wire spray arc welds. Metal transfer from cored wires is dominated by the flux type and there is no sharply defined transition current from globular to spray.

The other major difference, compared with solid wires, is that cored wires do not require argon-rich shielding gas for spray transfer. The EXXT-1 and -2 grades of flux-cored wires produce spray transfer over a wide range of currents in carbon dioxide or argon-carbon dioxide mixtures. Some of the modern T-1 wires give as smooth an arc in carbon dioxide as earlier wires did in argon-based gases.

Metal-cored wires are generally classified as T-1 types by AWS because they give spray arcs with argon-rich gases that contain 2% or 5% oxygen, or up to about 10% CO₂.

A major benefit of cored wires is that smooth spray transfer can be extended down to lower currents than can be used with solid wires. This means that it is not necessary to resort to short-circuiting transfer. Even at low currents the arc is continuous and it gives good fusion with less spatter, making flux-cored wires ideal for all-position welding.

Short-circuiting or dip transfer

At low currents (below the transition from globular to spray), globular transfer can be modified by the applied voltage. If the voltage is lowered, the arc length will become shorter until the wire eventually touches the surface of the weld pool. This causes a short circuit and the current rises to very high values, dependent on the characteristics of the power source. The end of the wire then melts off (like a fuse wire) and the arc is re-started. By control of the arc voltage and the rate of rise of the current (by inductance or electronic control of the power source), spatter can be greatly reduced, but not eliminated. Metal is transferred only during the short-circuit period, when the wire is in contact with the weld pool, and the workpiece is melted only during the arcing period.

The small pool and low heat input are ideal for the welding of sheet in all welding positions, which is the major application of short-circuiting transfer solid wire welding. Short-circuiting transfer welding of thick sections requires skill to prevent unacceptable defects, mainly poor fusion in the root and against the side walls. It is the lack of understanding, training, and skill that have given short-circuiting transfer welding a deservedly bad reputation. For example, dip transfer is not allowed in most structural welding because it is difficult to ensure its soundness and quality.

Short-circuiting or dip transfer is generally not required in the use of flux-cored wires (which produce slag to support the weld pool), but it is necessary with metal-cored wires for positional welding and therefore needs some discussion. The main applications of short-circuiting transfer are (1) the welding of steel sheet and thin plate with solid wires having diameters in the range of 0.6-1.2 mm where shallow penetration and low arc energy are required, and (2) positional welding of light structural steel where only a very small weld pool can be used because there is no slag to support the weld pool.

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Pulsed spray transfer

Since the early 1970's, there has been a growing interest in power sources that can supply current pulsed with controlled peak currents, background currents, peak widths and pulsing frequencies. Pulsed welding offers the possibility of (1) reduced spatter and (2) improved quality, mainly as a result of improved fusion in all-position welds. The objective of the pulsing is to produce spray transfer which propels a droplet during each current peak, after which the current is lowered to a background level that keeps the arc alight, but does not produce a large weld pool as it would if the current continued at a steady spray level. Pulsing combines the benefits of the cleanliness, directional transfer, and improved penetration of spray transfer with the smaller weld pool of short-circuiting transfer. This makes it useful for all-position welding of heavy steel sections, instead of short-circuiting transfer, thereby making it a competitor with cored wire welding.

Pulsed MIG/MAG welding is an area of much interest which has not been thoroughly explored, but pulsing capability is being incorporated into many power sources and welding engineers should keep themselves informed of progress.

MIG/MAG positional capability and electrode sizes

In conventional MIG/MAG welding a continuous solid wire electrode is fed at constant speed into a regulated arc that is protected by a gas shield. No flux is present and the only slag that forms is the result of deoxidation by silicon and manganese. Only very small weld pools can be supported in positional welding. High wire feed speeds and correspondingly high currents give high deposition rates that can be used only in flat and horizontal positions.

MIG/MAG wires are generally available in 0.6, 0.8, 0.9, 1.0, and 1.6 mm sizes. Because solid wires produce virtually no slag to support the weld pool, positional weld pools are held in place only by surface tension. If the pool becomes too large it will fall out. Large currents lead to large weld pools. Therefore, positional welding is possible only with relatively small pools produced at low currents, but if we are making a flat or horizontal MIG/MAG weld with, say, 1.2 mm wire at 200 A, we cannot simply turn down the current to make a positional weld because the arc becomes unstable.

Positional welding with solid MIG/MAG or metal-cored tubular wires is possible with either dip transfer or pulsed spray transfer. Dip transfer is suitable for thin sections but thick sections require higher heat input to ensure adequate fusion, and dip transfer is likely to cause lack-of-fusion defects, especially in roots and against side walls.

MIG/MAG shielding gases

The major shielding gases used for MIG/MAG welding of steels are:

- carbon dioxide, CO₂
- argon-CO₂ mixtures, typically 10% (spray transfer) or 20% (globular transfer)
- argon-oxygen (2% or 5%) for stainless steels
- argon-helium-CO₂ (for higher arc voltages)

Aluminium alloys are welded with pure argon or argon-helium mixtures (when extra heat is required).

Always check that the correct gas is being used.

Cored wire welding, *flux-cored arc welding (FCAW)*

Recent years have seen significant increases in the use of cored wires. These wires are hollow tubes filled with mixtures of metal and flux powders (flux-cored wires) or with metal powders only (metal-cored wires). The flux constituents provide similar benefits to the coatings on stick electrodes, and flux-cored wires have been described as "inside-out sticks", although the shielding gas is usually supplied as a separate external shield around the arc. Metal-cored wires do not produce significant slag

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cover, so they are used mainly for high deposition rate welds in flat and horizontal positions. Neither British Standards nor AWS have yet made sufficient distinction between metal-cored and flux-cored wires, but a metal-cored classification will be included in the new BS EN 758 when it is published.

Metal-cored wires have exceptional arc stability and are superior to solid wires, especially at high deposition rates. Because it is much cheaper to add elements such as chromium as a powder in the core, than to make the wire from solid chromium alloy steel, metal-cored wires provide flexibility in alloy additions.

Flux cores add alloying elements and provide slag cover that makes it possible use higher deposition rates than any other process in positional welding. Most flux-cored wires are gas shielded but self-shielded (gasless) wires are also available and should always be considered for site welding.

Cored wire positional welding capability and electrode sizes

The positional welding capability of cored wires is indicated in their classification. Metal-cored wires do not offer any significant advantages for positional welding because they must be operated in dip transfer or pulsed transfer modes. Metal-cored wires are sold in 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, and 2.0 mm sizes.

Flux-cored wires are sold in sizes from 0.8 up to 3.2 and 4.0 mm. Positional welding capability is very good in sizes up to 2.0 mm, but the smaller wire wires are becoming very popular because of the ease of use, although their price increases significantly at small diameters. The main benefit is good productivity and improved quality compared with MMA and MIG/MAG welding.

When substituting a cored wire for a solid wire, it is not necessary to use the same diameter. Flux-cored wires are suitable for positional welding in sizes up to 2.0 mm.

There is no advantage in using metal-cored wires for positional welding because dip transfer must be used. Metal-cored wires are especially good for high speed welding in the flat and horizontal positions under spray transfer conditions.

Metal-cored wire shielding gases

Metal-cored wires always require a gas shield. The most common shielding gases are:

- carbon dioxide, CO₂
- argon-CO₂ mixtures, typically 10% (spray transfer) or 20% (globular transfer)

Metal-cored wires give especially smooth metal transfer when using argon-10% CO₂ or other gas mixtures that give spray transfer.

Flux-cored wire shielding gases

Flux-cored wires often contain arc stabilizers that give smoother metal transfer than is possible with solid wires in argon-20%CO₂ or pure CO₂. High argon content gases or helium mixtures are not necessary with flux-cored wires.

Self-shielded wires do not need external shielding gas because their core contains all the ingredients necessary to deal with contamination from the air around the arc.

Submerged arc welding, SAW

Normally submerged arc welding is used as an automatic process, but it is important to remember that all continuous wire processes can be used manually (semi-automatic) or in mechanized forms (automatic).

In submerged arc welding, the arc is protected by a layer of flux powder that is laid around or in front of the wire along the path of the weld. The wire is pushed through the powder to strike an arc when it touches the workpiece. Because the arc is always under the protective powder, it cannot be seen and it must be steered along the correct

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path by mechanical or manual means. The presence of the flux layer results in the benefits of no arc glare and very little or no fumes, and complete freedom from spatter.

Submerged arc welds typically have very good quality, which has led to the process being used for critical fabrications including pressure vessels, offshore structures, etc, and any fabrication that can be tackled with the process. The welds are sound, uniform in shape, and have excellent surface quality. Although it associated mainly with heavy section welds, it is also ideal for sheet metal joints because of its minimal distortion and freedom from spatter compared with other arc processes.

Welding power can be DC+ve, DC-ve, or AC, supplied by drooping or flat characteristic power sources. The early sets ran with constant current (drooping output) power, and arc was regulated by controlling the wire feed speed from the arc voltage. When the arc became too long, the arc voltage rose and speeded up the feed motor. This is satisfactory for welds made at high currents with wires larger than about 3.2 mm. Early submerged arc welds were made at currents up to 2000 A on a single 6.3 mm wire, but the need for higher weld metal toughness led to the use of lower currents on smaller wires to give smaller weld beads. The inadequate response of the mechanical control of wire feed speed, at high feed speeds, led to the use of flat characteristic output (constant voltage) in which the feed speed stays constant and the arc is regulated by rapid changes in welding current.

DC+ve polarity is used for most submerged arc welds because its deep penetration gives excellent quality with little possibility of lack of fusion. The deep penetration provides several benefits that should be used. In structural work, such as bridges, the leg length of fillet welds can be reduced, and butt welds to thicknesses of at least 12 mm can be made with square edges and one pass from each side that penetrates more than 50% of the thickness.

At the same welding current, DC-ve polarity will give shallower penetration and higher deposition rates than with DC+ve, making DC-ve ideal for surfacing applications, especially if long stick-out is also used. Submerged arc welding is the most common method for building up and hardfacing of worn components, such as earth moving equipment, steel mill rolls, etc.

AC polarity is used where arc blow can be a problem with DC welding current. Heavy fabrications, especially in alloy steels are best welded with AC. Deposition rates and penetration with AC are between those of DC+ve and DC-ve.

Equipment

Submerged arc welds are often made with currents that might be as high or more than 1000 A, and with wires having diameters up to 4 or 5 mm, and the time required for a single pass on a large fabrication may be more than 10 minutes.

For heavy fabrications the equipment must be sturdy with capability of feeding thick wires, and the power source must be rated for 100% duty cycle.

Normally the equipment consists of three parts:

1. The equipment required for moving the workpiece relative to the welding head, or vice versa. The most common pieces of equipment for submerged arc welding are columns and booms, positioners, and rotaters.
2. The welding head, which usually consists of the wire feeder and a control box.
3. The power source nowadays is a rectifier (either constant voltage for smaller wire sizes, constant current for larger wire sizes, or multi-process), or a transformer for constant current AC.

For structural work it is often more convenient to use tractors that combine the feeder and control box with mechanisms for controlling travel speed. Tractors are very useful for applications such as deck welding, and making fillet welds on long beams

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Most submerged arc welding equipment is for dealing with large fabrications, but semi-automatic equipment is available for use with wires to 2.4 mm diameter. The equipment can be used with light fixtures for jobs such as attaching flanges to pipes, or it can be used manually for making welds with regular or irregular paths, such as fillet welds around the bases of columns being joined to base plates. For semi-automatic welding the gun feeds flux around the wire instead of shielding gas. The flux can be fed from a small hopper on the gun itself, or through a hose from a pressurised tank.

Advantages and limitations of submerged arc welding

The advantages are:

- Excellent weld quality - deep penetration, little or no porosity, excellent surface finish,
- High deposition rates,
- High travel speeds,
- Uniformity and reproducibility.

The major limitation is that the flux must be retained around the arc. This limits the process to welds made in the flat or horizontal positions, although the horizontal seams of many oil storage tanks have been welded with automatic machines that retain the flux against the wall of the tank by means of a flexible belt running on idler rolls attached to the welding head.

Submerged arc welding is capable of high travel speeds and deposition rates, especially when more than one electrode wire is used. Pipe mills use up to five wires, all feeding into the same weld pool, to obtain maximum welding speeds in heavy wall thicknesses. Care has to be taken to avoid each arc causing interference with its neighbours. Sometimes the DC-AC combination is used or AC-AC-AC with proper phase control.

The process is most commonly used with automatic equipment to make either straight line or cylindrical welds. Tractors provide more flexibility and manual semi-automatic welding with suitable guidance (although the arc cannot be seen) can be used for butt welds and fillet welds. In semi-automatic submerged arc welding flux is fed down the hose and through the gun, instead of shielding gas.

Because the process is the first choice for critical applications, such as large pressure vessels, its other capabilities are often neglected. The arc is contained under the flux burden and consequently the process will give good weld shape at speeds much higher than most other processes. Submerged arc welding is ideal for thin sheet because the high travel speeds give low heat input and less distortion than other processes, and there is no spatter to be cleaned up. It is an excellent process for making stainless steel equipment for the food, chemical, and pharmaceutical industries because minimum clean-up is required after welding.

When planning a submerged arc weld, the following steps should be taken:

1. Design the weld to enable it to be made with submerged arc welding.
2. Choose the wire and flux types for the application.
3. Choose the current, voltage and travel speed to be used.
4. Choose the wire diameter to handle the current.
5. Set up the edge preparation and positioning equipment to ensure uniformity.
6. Run a trial weld, examine penetration, and weld quality.
7. Adjust conditions if necessary, re-examine, and when satisfactory stay with those conditions.

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Electroslag and electrogas processes

Vertical welds in thick sections are very expensive to make by MMA, MIG/MAG, and FCAW because deposition rates are limited. For heavy structural work, storage tanks, and ship construction, the electroslag and electrogas processes should be considered.

Both processes make a single-pass weld across the full cross-section of the plate using copper dams to retain the molten weld metal. The dams can be fixed, running the complete height of the weld, or they can be small dams that are moved up the joint as the weld progresses.

When fixed dams are used the electrode wire is guided along the centre-line of the weld by a steel tube that is melted into the weld pool, as it rises up the tube.

When movable dams are used the wire is fed into the pool through a gun.

The molten metal is covered by a slag in electroslag welding, and the heat to melt the wire and the faces of the weld is generated by resistance heating of the slag, not by arc heat.

In electrogas welds, an arc between the wire and the weld pool is protected by a shielding gas, or by the use of a flux in the centre of a tubular wire.

The use of electroslag welding for structural work has declined because weld metal toughness is often inadequate, but electrogas welds are suitable for many applications, and for the right job it is by far the cheapest process. Sections, up to 100 mm thick can be welded in one pass by using four guide tubes, or by oscillating a single guide tube between fixed or movable dams.

Choice of welding process

A number of factors are considered when choosing which process to use:

- a. Shop or site welding conditions.
- b. Number of pieces to be produced.
- c. Welding positions that can be used.
- d. Availability of approved procedures.
- e. Availability of approved welders.
- f. Availability of suitable equipment.
- g. Cost of purchased or hired equipment.
- h. Welding times (deposition rates x operating factors) required for different processes.
- i. Edge preparations required.
- j. Clean-up required after welding.
- k. Reliability of process.

NOTES

General

BS 499 : Part 1 defines thermal cutting as: 'The parting or shaping of materials by the application of heat with or without a stream of cutting oxygen'.

The heat source applied for cutting may be either gas flame or electric arc.

Flame cutting processes

General

Carbon and low alloy steels are the only metals usually considered as being suitable for flame cutting. These are usually cut using the oxy-acetylene process, although alternative fuel gases such as propane and natural gas can be used, these provide a lower flame temperature and are generally (though not always) less efficient. Other fuel gases, e.g. hydrogen, may be used for specialised processes.

Flame types

The terms *neutral*, *oxidizing* and *carburizing* would normally be used to define the types of oxy-acetylene gas flames. See also diagrams in Unit W3-4.

The neutral flame:

This flame has equal quantities of oxygen and acetylene. It is used for the cutting of all carbon steels, and can be used on stainless steel if iron powder injection is used to produce the necessary chemical reaction on the otherwise oxide resisting surface, however, this is more of a *severing* process rather than a cutting process.

The oxidizing flame:

This flame has an excess of oxygen. It has no practical application area in cutting.

The carburizing flame:

This flame has an excess of acetylene. It is used for the cutting (severing) of cast iron; see W4.3 *The flame cutting of cast iron*.

Procedure for flame cutting

A heating flame is used to raise a spot of the metal to be cut to its ignition temperature, i.e. 870°C+. Steel heated to this temperature instantly oxidises to magnetic oxide of iron (Fe_3O_4) when subjected to a high pressure oxygen jet. This oxide has a melting point well below the steel from which it was formed and is therefore immediately melted and blown away in the oxygen stream leaving a cut, or *kerf*, approximately 1.5 mm wide.

Oxygen and cutting gas selection

Oxygen as the supporter of combustion is an essential part of the preheating flame. There is a choice of fuel gases to use with the oxygen. The most common fuel gases are acetylene, propane and methane (natural gas). Hydrogen may also be considered for underwater cutting.

The corresponding flame temperatures for these gases when combined with oxygen are as follows:

- Oxy-acetylene 3100°C
- Oxy-methane 2770°C
- Oxy-propane 2815°C
- Oxy-hydrogen 2825°C

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Flame cutting methods

Cutting may be performed manually using a hand torch, or by semi or fully automatic cutting machines. The construction of the cutting torches are essentially the same but each type has its advantages.

Whether hand or machine cutting is used, care should be taken to ensure that the cutting does not allow the work to collapse causing possible injury to the operator or damage to the machine/hoses etc..

Hand cutting

A considerable amount of practice is necessary to develop the skill required with hand cutting. Due to the difficulties in maintaining a consistent rate of travel, the cut made by hand cutting will usually be inferior to that made with a correctly operated machine. However the hand cutting torch is an invaluable tool in the fabrication industry particularly on-site where its total portability and versatility in the hands of a skilled operator make it superior to any other cutting technique. To improve the quality of cut, rollers and guides may be attached to the nozzle.

The fuel gas used with manual cutting is normally acetylene because the higher flame temperature gives shorter preheating times and assists in maintaining a continuous cutting action. Propane could be used, particularly for general purpose and demolition work etc., where the quality of cut is not of prime importance.

Semi-automatic cutting

Usually operated on-site, particularly for the cutting of pipe ends, semi-automatic flame cutting is a well established practice. The cutting torch, or *head*, is mounted on a wheeled carrier which in turn is attached to a track or chain device fitted around the pipe circumference.

When cutting commences the rate of progress is controlled by manually turning a handle which drives the cutter in the forward or reverse direction. It is possible for the cutting head to either traverse around the circumference of a fixed pipe, or for the cutter to remain stationary while the pipe rotates beneath it.

If a variable speed electric motor replaced the manual drive then it would be termed automatic and could also be used on flat plate operating on tracks or guides. The fuel gas used would normally be acetylene or propane.

Automatic cutting machines

Automatic cutting machines, commonly termed *profile cutters*, usually have a fixed base and are therefore typically encountered in fabrication shops etc.. These cutting machines have a very wide scope and will cut plates accurately to any required shape, either by magnetically following a steel template or by electronically following the outline of a drawing.

A big advantage of this type of machine is that multiple cutting heads and/or *stack* cutting can be used, greatly increasing production.

Because of the fine control associated with automatic cutting the fuel gas used could be acetylene, propane or even natural gas from the mains supply providing it is properly regulated and controlled.

The effect of flame cutting on steel

Flame cutting involves both rapid heat input and rapid heat loss. The overall effect of this, is increased hardness of the cut edge which rarely extends inwards for more than a distance of 3 mm. The degree and severity of the hardness encountered will be dependent upon the steel's carbon and/or alloy content. Steels with 0.3%C and below can normally be cut without any problems, the cut edge can be welded on directly (after basic cleaning) and the heat evolved from the welding process would be sufficient to remove any hard spots/areas present.

It is recommended that steels with a carbon content above 0.3% and/or with alloys of nickel, molybdenum, manganese and chromium (<5%) are subject to a preheat

Stack cutting involves the simultaneous cutting of a number of plates on top of each other.

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treatment to reduce the possibility of edge cracking. Post cut machining/grinding to remove 1-3 mm of the cut edge may also be necessary and may be specified in the procedure. Post-heat may also be a consideration.

Other factors affecting increased hardness include:

- the type of fuel gas used (flame temperature).
- the plate thickness; thick plates will harden more than thin plates due to faster heat dissipation.
- the cutting speed; the faster the cutting the more rapid the heat loss.

Flame cutting - special applications

General

As previously stated, flame cutting is normally only carried out on carbon and low alloy steels and usually in normal atmospheric conditions using a strictly neutral heating flame; it can however be used outside these criteria and specifically for:

- the flame cutting of cast iron,
- underwater flame cutting.

The flame cutting of cast iron

The flame cutting of cast iron is made difficult by the action of the silicon and graphite content which tend to resist oxidation, however, reasonable cuts can be made using the *oxy-acetylene* process. Pressures for both gases would typically be increased by a factor of 3 when compared to a similar thickness of carbon steel.

The flame used must have a large excess of acetylene, i.e. be of the carburizing type.

To overcome the tendency of the kerf to clog, a slight side to side weaving action of the nozzle is required.

The higher gas pressures necessary to maintain oxidation cause much higher levels of heat to be evolved; the process also produces very high levels of fume and appropriate precautions against both must be taken.

Underwater flame cutting

Underwater flame cutting is carried out by skilled divers on steel construction, repair and salvage work on ships, dry docks, pipelines, dams, piers, offshore rigs, tunnels etc..

Standard cutting torches may be used up to about 9 m depth but, as a rule, special underwater cutting torches fitted with air hoods or caps are used. These special torches are supplied with compressed air to form an air bubble around the nozzle, this keeps water away from the surface being cut and allows faster preheating. The latest torches concentrate the flame to achieve rapid preheat without the use of air hoods etc..

The fuel gases which can be used underwater are very limited, they either lack sufficient thermal output, begin to liquify as the pressure (depth) increases, or cannot be used at the high pressures required.

For example, the maximum draw off rate of acetylene is 15 p.s.i. (22 p.s.i. with H.S.E. approval). At 30 foot depth the pressure is 15 p.s.i., so no gas would come out of the nozzle; go any deeper and water would flow back into the equipment. Therefore acetylene is only used down to around 5-6 foot depth. Propane and natural gas lack the thermal output to be used at any depth.

LPG with methyl additives—such as *MAPP gas* and *Apache gas*—can be fed to the nozzle at up to 100 p.s.i.. These gases have thermal outputs close to acetylene and could be used from 0-150 foot depth; they are mainly encountered for underwater cutting in the USA. The normal practice for UK underwater cutting for both commercial and military use is to use hydrogen gas as the fuel, due to its ability to resist liquification even at the maximum depths encountered in the North Sea.

The heating flame gas needs to be kept 2-3 p.s.i. positive to the actual depth pressure with additional allowances being made for loss of pressure due to friction as depth and

*Water has a cooling action
approximately 40 times
greater than air.*

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hose length increase. The cutting oxygen would be maintained at 50-60 p.s.i. above depth pressure.

Electric arc cutting processes

General

Although there are other arc cutting processes, only the plasma arc process is considered here.

Plasma arc cutting

Plasma arc cutting uses the same power source and equipment as used for plasma arc welding. Higher current values (300-750 amps) and higher plasma gas pressures (45-120 ltrs/min) are used.

Both *non-transferred* and *transferred techniques* may be used, the arc temperature being in the range of 10,000°C to 24,000°C. The plasma cutting process may be operated either manually or as a semi or fully automatic unit. Plasma arc cutting will cut all electrically conducting materials including tungsten etc. but is mainly used on aluminium and stainless steels up to approximately 150 mm thick, although thicker cuts can be achieved.

The cut, or kerf, is produced by the action of the plasma first melting and, in some cases, vapourising the material. The material is then blown away by the high pressure gas stream. Cutting is instantaneous with no preheat time being necessary, the cut surface is similar to that achieved with the oxy-acetylene process, but no oxidation is present.

Plasma cutting produces a natural 5° bevel on the cut; this needs to be allowed for on the set up, however, the latest equipment is capable of giving a square cut.

Metallurgical effects are similar to oxy-acetylene cutting at high speed, with hardening of the cut face and possible cracking—dependent upon material—being the major problem.

Gouging processes

General

Gouging may be carried out by either a gas or arc process. The basic principles and equipment are the same as for welding but nozzle design and/or consumables may change. In all cases the heat source used for gouging is *pushed* along the line of travel.

Gouging may be used for the following reasons:

- a. spot removal of weld defects for repair,
- b. removal of tacked lugs, nuts, bolts etc.,
- c. piercing of metals to produce holes,
- d. back gouging of sealing runs in high quality welds.

Oxy fuel gas gouging

The only fuel gas with enough thermal energy for gouging is acetylene. The set up and starting techniques are the same as for oxy-acetylene cutting, but the angle of nozzle approach is shallower. The metal is removed to a predetermined depth governed by the nozzle size, speed of travel and the angle that the cutting oxygen meets the plate.

Grooving and gouging electrodes

These electrodes have the advantage of being able to be used with conventional m.m.a. equipment. The gouging electrode is a carbon coated steel cored electrode used at

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5-10° angle to the plate and pushed along the line of travel. They are particularly suited to site work where more precise methods/processes are not available, i.e. ideal for rougher work including the removal of lower quality welds, piercing holes and severing metals.

Oxy-arc

The oxy-arc process uses an electric arc struck between a hollow, flux covered steel electrode and the work. High pressure oxygen passes through the electrode which is held in a special gun type holder with oxygen control.

Gouging of carbon, low alloy and stainless steels is commonly carried out to a high quality, but the gouging of non-ferrous metal will require mechanical finishing, as would severed faces of all metals prior to welding. This process, with minor modifications to the equipment, can be used underwater.

The arc-air process

The arc-air process maintains an arc between a copper coated carbon electrode and the work. Twin jets of trigger controlled compressed air emerge from the head of the electrode holder, one either side of the electrode, and converge at the arc to blow away the molten metal. The surface produced is generally suitable for welding with minimal dressing to remove a thin film of deposited carbon which can cause subsequent lack of fusion if welded over.

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GOOD CUT

Sharp top and bottom edges. Vertical drag lines no adhering dross, square face. Light easily removed oxide scale.



CUTTING SPEED TOO FAST

Top edge not sharp. Rounded bottom edge which may not be completely severed. Drag lines uneven sloping backwards irregular cut edge.



CUTTING SPEED TOO SLOW

Rounded and melted top edge, bottom edge rough. Dross on bottom edge difficult to remove. Lower part of cut face irregularly gouged heavy scale on cut face.



NOZZLE TOO HIGH

Excessive melting of top edge. Undercut at top of cut face.



IRREGULAR CUTTING SPEED

Wavy cut edge uneven drag lines.



PREHEATING FLAME TOO HIGH

Rounded top edge, irregular cut edge, melted metal falling into kerf. Excessive amount of dross adhering strongly to bottom edge.



PREHEATING FLAME TOO LOW

Bad gouging of lower part of cut face cutting speed slow.



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Steel

There are many types of steel, all of which are alloys based on iron. Physical, chemical and metallurgical properties may vary substantially between different types of steel and some are more weldable compared to others.

The properties of steels are governed by the elements and compounds that make up the steel, the final grain structures present and condition of the steel, e.g. as rolled. The content of steel is carefully determined by adding alloys and removing impurities and excess amounts of elements or compounds already present. The content of the steel will influence the final grain structure although other factors such as deoxidation, cooling rates, hot working, cold working and post-heat treatment may play a major part.

Many elements may be present in a steel, some of which are added or reduced to certain levels to produce specific properties, for example:

- Carbon (C) - The key element in steels. Has a major influence on strength, toughness, ductility and hardness.
- Manganese (Mn) - Primary desulphuriser and secondary deoxidizer. Often added in order to enable the carbon content to be reduced. Affects strength and hardenability.
- Silicon (Si) - Primary deoxidizer. Reduced toughness if too much exists.
- Aluminium (Al) - Grain refiner and tertiary deoxidizer.
- Molybdenum (Mo) - Improves creep resistance and reduces temper embrittlement.
- Chromium (Cr) - Improves hardness and resistance to wear. In stainless steels it is added for corrosion resistance.
- Nickel (Ni) - Improves ductility, strength and toughness. In austenitic stainless steels it improves resistance to corrosion from acids.

Most steel elements when present in undesirable amounts may be considered as impurities. Sulphur (S) and phosphorus (P) in particular, are usually kept to levels below ~0.05%, because sulphur may promote *hot shortness* and phosphorus may promote *cold shortness*.

Hot shortness is the susceptibility of a material to cracking during hot working.

Cold shortness is the susceptibility of a material to cracking during cold working.

Grain structures

The grain structure of a material will influence its weldability, its mechanical properties and in-service performance. The type and number of grain structures present in a material will be primarily influenced by three factors: (1) the elements in the material, (2) the temperatures reached during welding and/or post-weld heat treatment and (3) the cooling rates produced. Single or multiple grain structures may be present in a material in its final state.

Austenite

Austenite is the high temperature form of C, C-Mn and alloy steels which exists above 723°C. The temperature at which the steels are fully austenitic depends on carbon content, e.g. low carbon <0.1%C - over 910°C; 0.8%C about 730°C.

The *cooling rate* from the austenite region determines the hardness of the steel at room temperature. Very slow cooling produces very soft steels; medium cooling rates produce soft to medium steels; fast cooling can produce very hard and brittle steels depending on the carbon content and thickness of the steel.

NOTES

Cementite is iron carbide (Fe_3C).

Ferrite

Ferrite is essentially pure iron at room temperature, it contains either very little or no carbon. This grain structure is formed from the austenite region by holding at a temperature which depends on the carbon content of the steel, e.g. 910°C for low carbon steel. Ferrite is very soft and ductile and has low tensile strength but has good machining properties.

Pearlite

Pearlite forms from the austenite region under slow cooling and consists of plates of ferrite and cementite, it is harder than ferrite because of the layers of hard cementite it contains. Pearlite is the most frequently encountered grain structure in a constructional steel.

Bainite

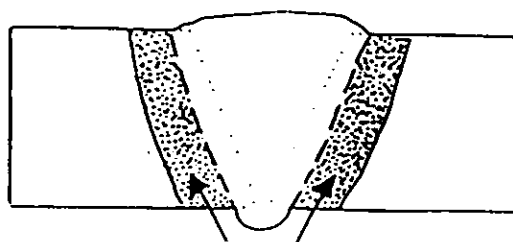
Bainite forms from the austenite region when the cooling rate is too fast for pearlite to form, it is harder and usually tougher than pearlite. Bainite often forms in the h.a.z. area of C-Mn steel welds.

Martensite

Martensite is a very hard and brittle grain structure but it can be tempered in order to improve toughness. It is formed from the austenite region by quenching or very fast cooling. This grain structure can only be formed in plain steels when sufficient carbon exists, usually over 0.3%. For alloy steels this figure may be much lower because other alloys in the steel - especially chromium - also have an influence. Unless specifically designed into the steel, the presence of martensite should be avoided.

The heat affected zone (h.a.z.)

During welding using a fusion welding process there is a huge temperature difference between the weld and parent material. Because of this temperature difference, the material immediately adjacent to the weld undergoes microstructural changes. This area, which lies between the fusion boundary and the unaffected parent material, is called the heat affected zone (h.a.z.).



Heat affected zone

NOTES

$\text{Volts} \times \text{Amps} = \text{Watts}$

$1 \text{ V} \times 1 \text{ A} = 1 \text{ watt} = 1 \text{ J/sec}$

The extent of the changes in microstructure will depend on the following:

- Material composition; especially carbon content.
- Heat input. The higher the heat input or *arc energy*, the wider the heat affected zone. Metallurgical properties will also be affected.

$$\text{Arc energy (kJ/mm)} = \frac{\text{Volts} \times \text{Amps}}{\text{Travel speed (mm/s)} \times 1000}$$

- The rate of cooling. The faster the rate of cooling the harder the heat affected zone, especially if the *carbon equivalent* of the steel is high.

The h.a.z. of a fusion weld on steel consists of up to four separate regions of microstructure, the actual condition will be dependant upon the alloying elements present and the thermal conditions applied during welding. The following grain structures—starting from the area immediately adjacent to the weld—are typically present on a 0.15% C steel:

- A coarse grained region (heated between 1100°C and melting point).
- A grain refined region (900 to 1100°C).
- A region of partial transformation (750 to 900°C).
- A region of spheroidization (just below 750°C).

On C-Mn and low alloy steels, the h.a.z. of the weld tends to be more brittle, i.e. it has a lower notch toughness, than the actual weld metal. The h.a.z. area is therefore more prone to cracking, especially when hydrogen induced, although it must be noted that the tensile strength of the h.a.z. is normally high in comparison with the weld and parent material. Unfortunately, if a fusion welding process is being used, the heat affected zone cannot be eliminated, although it can be controlled using a properly applied welding procedure.

The effect of hydrogen in steel

The presence of hydrogen causes general embrittlement in steel and during welding may lead directly to cracking of the weld zone. The following terms are forms of hydrogen related problems:

- hydrogen induced cold cracking (h.i.c.c.), using heat affected zone crack.
- fissures/micro-fissures } usually weld body cracks.
- chevron cracks,
- fish-eyes. -hydrogen inclusions.

Mechanism

The following text describes the mechanisms believed to be involved with the formation of *hydrogen induced cold cracking (h.i.c.c.)* in steel:

Hydrogen enters a weld via the welding arc. The source of hydrogen may be from moisture in the atmosphere, contamination on the weld preparation, or moisture in the electrode flux. With the m.m.a. and s.a.w. processes, the selection of flux type will also affect the H₂ content.

The intense heat of the arc is enough to breakdown the molecular hydrogen (H₂) into its atomic form (H). Hydrogen atoms are the smallest atoms known to man and therefore can easily infiltrate amongst the iron atoms while the weld is still hot. When the weld area is hot, the iron atoms are more mobile thereby producing larger gaps between themselves, i.e. the steel is in an expanded condition.

High Strength Low Alloy (HSLA) steels tend to suffer from fissures/micro-fissures and chevron cracks

NOTES

As the weld cools down most of the hydrogen diffuses outwards into the parent material and atmosphere, but some of the hydrogen atoms become trapped within the weld zone. This is due to the iron atoms settling as the weld cools, therefore the gaps between them become smaller, i.e. the steel is contracting.

Below -200°C the element of hydrogen prefers to be in its molecular form (H_2), the individual atoms of hydrogen are attracted towards each other as the weld cools and they congregate in any convenient space as microscopic gas bubbles.

When the hydrogen molecules exist in large numbers, a lot of pressure is exerted—60,000 to 200,000 p.s.i.! Because of this internal pressure, the adjacent grain structure may react in one of two ways:

1. It may deform slightly to reduce the pressure. This will occur if the surrounding metal is ductile e.g. pearlite.
2. It may separate completely to reduce the pressure i.e. crack. It will occur if the surrounding metal is brittle e.g.

1. It may deform slightly to reduce the pressure. This will occur if the surrounding metal is ductile e.g. pearlite.
2. It may separate completely to reduce the pressure i.e. crack. It will occur if the surrounding metal is brittle e.g. martensite.

if susceptible

Weld fractures associated with hydrogen are more likely to occur in the h.a.z. as this area tends to have increased brittleness. It must also be observed that it usually takes an external stress to initiate and propagate a crack. Lower temperatures will decrease the fracture toughness of the steel and at the same time increase H^2 pressure.

Conclusion: before hydrogen cracking occurs the following criteria must exist:

- hydrogen
- a grain structure susceptible to cracking (martensite is particularly susceptible)
- stress
- a temperature below -200°C

To reduce the chance of hydrogen cracking:

- ensure good preparation (hydrogen cracking)
- preheat (preheating are clean)
- use a low hydrogen electrode (70 Dnp 2) slows cooling rate, aids H dispersion
- use a multi-pass welding technique (Heat treatment of previous run, heat treatment)
- use H_2 release post-heat treatment

Hydrogen scales

The following chart shows terminology used by the International Institute of Welding (IIW) and BS 5135 with regard to hydrogen levels per 100 grams of weld metal deposited:

H_2 Content (ml)	IIW	BS 5135
> 15	High	Scale A
$\geq 10 \leq 15$	Medium	Scale B
$\geq 5 < 10$	Low	Scale C
< 5	Very low	Scale D

Hydrogen content of weld processes

The hydrogen content in a specific weld depends on a variety of factors such as the degree of contamination on the weld preparation, the arc length used, the amount of water vapour in the immediate environment and cooling rate of the weld. However, it is still possible to approximate hydrogen contents of welds made under typical well controlled conditions. The amount of hydrogen remaining in a weld - assuming no hydrogen release post-heat treatment process has been used - will depend largely on the

NOTES

welding process used. Shown below are welding processes with hydrogen levels achieved per 100 grams of weld metal deposited:

1. T.l.g. - < 1 ml is possible.
2. M.l.g./m.a.g. - < 2 ml is possible.
3. Electroslag - > 3 ml is likely. - Reason is no arc.
4. M.m.a. - < 5 ml possible for high temperature baked basic electrodes, but could be as much as 70 ml for certain cellulose electrodes.
5. Submerged arc - > 5 ml but could be as much as 50 ml. Depends on flux type and heat treatment of flux.
6. Flux cored m.a.g. - > 10 ml is likely.

The carbon equivalent of steel

The $C_{eq}\%$ of a steel primarily relates to its *hardenability*. If a steel has a relatively high $C_{eq}\%$ it will be more susceptible to hardening in the heat affected zones of any welds made, in comparison with welds made on steels of low $C_{eq}\%$. Hardenability affects *weldability*, therefore materials of high $C_{eq}\%$ are considered more difficult to weld.

The $C_{eq}\%$ of a material depends on its alloying elements. The typical elements in a high-grade carbon manganese steel are as follows:

Iron (Fe)	Silicon (Si)
Carbon (C)	Titanium (Ti)
Manganese (Mn)	Niobium (Nb)
Chromium (Cr)	Aluminium (Al)
Vanadium (V)	Tin (Sn)
Molybdenum (Mo)	Sulphur (S)
Nickel (Ni)	Phosphorus (P)

The $C_{eq}\%$ of a low alloy steel is usually calculated from the *I.I.W. carbon equivalent formula*:

$$C_{eq}\% = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

Only carbon and manganese have any significant effect on the final $C_{eq}\%$ figure on carbon/carbon manganese steels, therefore the formula may sometimes be shortened to:

$$C_{eq}\% = C + \frac{Mn}{6}$$

0.1% C has the same effect on hardenability compared to 0.6% Mn, therefore the manganese content is divided by 6 because one part of Mn has one sixth of the effect on hardenability compared to one part of C.

A carbon equivalent value less than approximately 0.4% would be considered *low* for a low alloy steel (this includes C-Mn steel).

EXAMPLE

What is the Ceq% of a steel which contains 0.12% carbon and 1.3% manganese?

a. $Ceq\% = C + \frac{Mn}{6}$

b. $Ceq\% = 0.12 + \frac{1.3}{6}$

c. $Ceq\% = 0.12 + 0.216r$

d. $C_{eq} = 0.336\%$

The gas used for preheating is usually oxy-propane.

Induction systems use high frequency a.c. induction magnets.

Preheat is the application of heat to a joint prior to welding and is usually applied by a gas torch or induction system.

Preheat is an expensive operation and is therefore only carried out when necessary, i.e. if there is a significant chance that adverse metallurgical structures and/or cracks could occur.

Preheat temperatures on steel pipe and many steel structures are arrived at by taking into consideration the carbon equivalent, the material, the material thickness and the arc energy. Reference may be made to standard specifications, *API Spec 5L*, *ASME B31.3*, *ASME B31.1*, *ASME B31.4*, *ASME B31.9*, *ASME B31.12*, *ASME B31.13*, *ASME B31.14*, *ASME B31.15*, *ASME B31.16*, *ASME B31.17*, *ASME B31.18*, *ASME B31.19*, *ASME B31.20*, *ASME B31.21*, *ASME B31.22*, *ASME B31.23*, *ASME B31.24*, *ASME B31.25*, *ASME B31.26*, *ASME B31.27*, *ASME B31.28*, *ASME B31.29*, *ASME B31.30*, *ASME B31.31*, *ASME B31.32*, *ASME B31.33*, *ASME B31.34*, *ASME B31.35*, *ASME B31.36*, *ASME B31.37*, *ASME B31.38*, *ASME B31.39*, *ASME B31.40*, *ASME B31.41*, *ASME B31.42*, *ASME B31.43*, *ASME B31.44*, *ASME B31.45*, *ASME B31.46*, *ASME B31.47*, *ASME B31.48*, *ASME B31.49*, *ASME B31.50*, *ASME B31.51*, *ASME B31.52*, *ASME B31.53*, *ASME B31.54*, *ASME B31.55*, *ASME B31.56*, *ASME B31.57*, *ASME B31.58*, *ASME B31.59*, *ASME B31.60*, *ASME B31.61*, *ASME B31.62*, *ASME B31.63*, *ASME B31.64*, *ASME B31.65*, *ASME B31.66*, *ASME B31.67*, *ASME B31.68*, *ASME B31.69*, *ASME B31.70*, *ASME B31.71*, *ASME B31.72*, *ASME B31.73*, *ASME B31.74*, *ASME B31.75*, *ASME B31.76*, *ASME B31.77*, *ASME B31.78*, *ASME B31.79*, *ASME B31.80*, *ASME B31.81*, *ASME B31.82*, *ASME B31.83*, *ASME B31.84*, *ASME B31.85*, *ASME B31.86*, *ASME B31.87*, *ASME B31.88*, *ASME B31.89*, *ASME B31.90*, *ASME B31.91*, *ASME B31.92*, *ASME B31.93*, *ASME B31.94*, *ASME B31.95*, *ASME B31.96*, *ASME B31.97*, *ASME B31.98*, *ASME B31.99*, *ASME B31.100*, *ASME B31.101*, *ASME B31.102*, *ASME B31.103*, *ASME B31.104*, *ASME B31.105*, *ASME B31.106*, *ASME B31.107*, *ASME B31.108*, *ASME B31.109*, *ASME B31.110*, *ASME B31.111*, *ASME B31.112*, *ASME B31.113*, *ASME B31.114*, *ASME B31.115*, *ASME B31.116*, *ASME B31.117*, *ASME B31.118*, *ASME B31.119*, *ASME B31.120*, *ASME B31.121*, *ASME B31.122*, *ASME B31.123*, *ASME B31.124*, *ASME B31.125*, *ASME B31.126*, *ASME B31.127*, *ASME B31.128*, *ASME B31.129*, *ASME B31.130*, *ASME B31.131*, *ASME B31.132*, *ASME B31.133*, *ASME B31.134*, *ASME B31.135*, *ASME B31.136*, *ASME B31.137*, *ASME B31.138*, *ASME B31.139*, *ASME B31.140*, *ASME B31.141*, *ASME B31.142*, *ASME B31.143*, *ASME B31.144*, *ASME B31.145*, *ASME B31.146*, *ASME B31.147*, *ASME B31.148*, *ASME B31.149*, *ASME B31.150*, *ASME B31.151*, *ASME B31.152*, *ASME B31.153*, *ASME B31.154*, *ASME B31.155*, *ASME B31.156*, *ASME B31.157*, *ASME B31.158*, *ASME B31.159*, *ASME B31.160*, *ASME B31.161*, *ASME B31.162*, *ASME B31.163*, *ASME B31.164*, *ASME B31.165*, *ASME B31.166*, *ASME B31.167*, *ASME B31.168*, *ASME B31.169*, *ASME B31.170*, *ASME B31.171*, *ASME B31.172*, *ASME B31.173*, *ASME B31.174*, *ASME B31.175*, *ASME B31.176*, *ASME B31.177*, *ASME B31.178*, *ASME B31.179*, *ASME B31.180*, *ASME B31.181*, *ASME B31.182*, *ASME B31.183*, *ASME B31.184*, *ASME B31.185*, *ASME B31.186*, *ASME B31.187*, *ASME B31.188*, *ASME B31.189*, *ASME B31.190*, *ASME B31.191*, *ASME B31.192*, *ASME B31.193*, *ASME B31.194*, *ASME B31.195*, *ASME B31.196*, *ASME B31.197*, *ASME B31.198*, *ASME B31.199*, *ASME B31.200*, *ASME B31.201*, *ASME B31.202*, *ASME B31.203*, *ASME B31.204*, *ASME B31.205*, *ASME B31.206*, *ASME B31.207*, *ASME B31.208*, *ASME B31.209*, *ASME B31.210*, *ASME B31.211*, *ASME B31.212*, *ASME B31.213*, *ASME B31.214*, *ASME B31.215*, *ASME B31.216*, *ASME B31.217*, *ASME B31.218*, *ASME B31.219*, *ASME B31.220*, *ASME B31.221*, *ASME B31.222*, *ASME B31.223*, *ASME B31.224*, *ASME B31.225*, *ASME B31.226*, *ASME B31.227*, *ASME B31.228*, *ASME B31.229*, *ASME B31.230*, *ASME B31.231*, *ASME B31.232*, *ASME B31.233*, *ASME B31.234*, *ASME B31.235*, *ASME B31.236*, *ASME B31.237*, *ASME B31.238*, *ASME B31.239*, *ASME B31.240*, *ASME B31.241*, *ASME B31.242*, *ASME B31.243*, *ASME B31.244*, *ASME B31.245*, *ASME B31.246*, *ASME B31.247*, *ASME B31.248*, *ASME B31.249*, *ASME B31.250*, *ASME B31.251*, *ASME B31.252*, *ASME B31.253*, *ASME B31.254*, *ASME B31.255*, *ASME B31.256*, *ASME B31.257*, *ASME B31.258*, *ASME B31.259*, *ASME B31.260*, *ASME B31.261*, *ASME B31.262*, *ASME B31.263*, *ASME B31.264*, *ASME B31.265*, *ASME B31.266*, *ASME B31.267*, *ASME B31.268*, *ASME B31.269*, *ASME B31.270*, *ASME B31.271*, *ASME B31.272*, *ASME B31.273*, *ASME B31.274*, *ASME B31.275*, *ASME B31.276*, *ASME B31.277*, *ASME B31.278*, *ASME B31.279*, *ASME B31.280*, *ASME B31.281*, *ASME B31.282*, *ASME B31.283*

Thicker materials normally require higher preheat temperatures, however, for a given Ceq% and arc energy, the preheat temperature is likely to be the same for wall thicknesses up to approximately 20 mm. A typical specification example of preheat temperatures for C-Mn steel 8-20 mm thick which is based on Ceq% values is as follows:

*For $C_{eq} \leq 0.4\%$ - minimum preheat 50°C

For $C_{eq} > 0.4 \leq 0.48\%$ " 100°C

For $C_{eq} > 0.48\%$ - minimum σ_{max} $\approx 200^{\circ}$

The welding inspector would usually find the preheat temperature to be used from the relevant welding procedure.

Preheating has many advantages:

- Preheat slows down the rate of hardening and also allows the carbon to diffuse out, thereby reducing the distortion caused by the application of a preheat before welding on the material.
- Preheat removes any moisture from the material.
- Preheat improves the crystalline structure of the metal.
- Preheat ensures more uniform cooling rates, which lowers the stress between the weld and parent metal.

Preheat temperatures may be measured by the use of a touch pyrometer (thermocouple) or temperature indicating crayons (Tempil sticks). Temperature indicating crayons exist in two forms: the type that melt, and the type that change colour. The method of temperature measurement to be used is sometimes stated in the specification for the work being carried out.

NOTES

If preheating is being applied and tack welding is carried out prior to the main welding, these tacks should also be preheated.

Preheat temperatures are measured at intervals along or around a joint to be welded. The number of measurements taken must allow the inspector to be confident that the required temperature has been reached over the full area to be welded. Specifications sometimes specify that the preheat temperature must be maintained over a specified distance from the joint faces, e.g. 50-100 mm.

The preheat temperature should be taken immediately prior to welding. If a gas heat source has been used, sufficient time must be allowed for the temperature to equalize throughout the thickness of the components to be welded, otherwise only the surface temperature will be measured. Time lapses vary depending on specification requirements, e.g. BS 5135 states 2 minutes for a 25 mm wall thickness.

Interpass temperature

The temperature of the joint during welding and between passes is known as the *interpass temperature*. It is often specified that the interpass temperature must not drop below the minimum preheat temperature.

NOTES

Weldability

Definitions

'A metallic material is considered to be weldable, to a certain degree, by a given process and for a given purpose, when a continuous metallic connection can be obtained by welding using a suitable procedure, so that the joints comply with the requirements specified both in regard to their local properties and their influence on the construction of which they form a part.' - *The International Institute of Welding (I.I.W.)*.

'The capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily in the intended service.' - *The American Welding Society (A.W.S.)*.

'The ease with which a material or materials can be welded to give an acceptable joint.' - *BS 499 : Part 1 : 1991 : Glossary for welding, brazing and thermal cutting*.

It is difficult to assess weldability in absolute terms; it is therefore usually assessed in relative terms.

Factors which affect weldability

1. Design:
 - a. access;
 - b. restraint.
2. Metallurgical properties:
 - a. structure and properties of the weld metal;
 - b. structure and properties of the h.a.z..
3. Physical properties:
 - a. thermal resistance;
 - b. coefficient of thermal expansion;
 - c. elastic modulus;
 - d. viscosity of molten material.
4. Chemical properties:
 - a. oxidation resistance;
 - b. surface films;
 - c. impurities.

NOTES

Steel types and their weldability

There are various ways to group steels, e.g. by composition, by use, by grain structure and by the primary property they possess. The following list shows steels identified by the common terminology used when they are referred to in industry:

Steel type	Main alloys	Comments	Weldability
Rimming steel	< 0.15% C	A form of low carbon steel which is not deoxidized.	Good, but the weld pool will require deoxidant(s) to be added via the filler consumable.
Balanced steel	< 0.3% C	A general construction steel.	Good, but an excess of certain residuals, especially sulphur, may lead to cracking.
Killed steel	< 0.26% C < 1.0% Mn	A deoxidized steel excellent for cold working. Includes mild steel.	Good, but an excess of certain residuals, especially sulphur, may lead to cracking.
Medium carbon steel	0.2-0.5% C	Used for forgings, shafts, gears ...	Fair. Susceptible to h.i.c.c. in the h.a.z. especially on thick sections.
High carbon steel	0.5-1.4% C 0.2-1.0% Mn	Mainly used for wear resistance.	Poor. Susceptible to h.i.c.c. in the h.a.z. and to solidification cracking.
Carbon manganese steel	< 0.27% C 0.3-1.4% Mn High grades contain V, Nb and Ti	Widely used high strength steel used in construction. Good toughness properties.	Good. The main problem is to maintain mechanical properties
Low temperature (cryogenic) steel	3.5-9.0% Ni	Applications such as storing and/or transporting liquid nitrogen, oxygen etc..	Good. High Ni content material is susceptible to solidification cracking.
High temperature creep resistant steel (Mo and Cr-Mo types)	0.2-0.3% Mo < 9.0% Cr	Service temperatures up to 600°C depending on steel type.	Good to poor depending on composition. Low Cr steels are difficult to weld.
Micro-alloyed steels (HSLA)	Small amounts of V, Nb and/or Ti.	These steels behave in a predictable manner	Good, but sometimes susceptible to h.i.c.c. in the weld metal.
Austenitic stainless steel	18-27% Cr 8-22% Ni < 0.08% C	Non-magnetic. Commonly welded steel used for a wide range of applications where corrosion resistance is a primary requirement.	Good. Problems with solidification cracking and weld decay may be encountered with unstabilized types.

Creep is the slow plastic deformation of a material under constant stress.

HSLA = high strength low alloy

*High Ductility.
Low Yield points.*

UNIT W6 • WELDABILITY OF STEELS

NOTES

Magnetic
High Ductility
Low strength (UTG)

Steel type	Main alloys	Comments	Weldability
Ferritic stainless steel	12-27% Cr <0.08% C	Not widely used in construction. Good for resistance to stress corrosion.	Poor. Susceptible to cracking and temper embrittlement. <i>Non hardenable (Not enough Carbon)</i>
Martensitic stainless steel	11% Cr 0.1-0.35% C	Not usually welded. Commonly used for cutlery and ball bearings. <i>Very high strength</i>	Very poor. Susceptible to hydrogen cracking. <i>Unweldable.</i>
Duplex stainless steel	21-23% Cr 4.5-6.5 Ni 2.5-3.5% Mo <0.03% C	A ferritic-austenitic steel. Good mechanical properties, abrasion and corrosion resistance. Combines the best properties of ferritic and austenitic stainless steel.	Good.

NOTES

Guidelines for the welding of steels

The following text gives further information on the use and weldability of the following materials:

- Carbon steels.
- Carbon-manganese steels.
- Low nickel alloy steels.
- 0.3 and 0.5 molybdenum steels.
- Low alloy chromium-molybdenum steels.
- Stainless steels - austenitic, ferritic, martensitic, duplex.
- Nickel and nickel alloys (*not a steel*).

Carbon and carbon-manganese steels

Carbon and carbon-manganese steels are typically used as construction material for piping, pressure vessels, supports and building structures.

Low-carbon steels are commonly used due to their good weldability. However, when improved mechanical properties are required, a steel is selected with an increased carbon and/or manganese content. These steels have a tensile strength above 450 N/mm², but their weldability is inferior.

For a combination of good weldability and improved mechanical properties fine-grained steels may be selected. These steels also have improved impact properties and are typically used for low-temperature service. For high temperature service, both carbon and fine-grained steels can be used, provided a p.w.h.t. is applied.

The weldability and weld quality of ferritic steels depends on the carbon content and the carbon equivalent.

Good weldability without the necessity for p.w.h.t. is usually obtained when the following criteria are met:

1. $C \leq 0.23\%$ for plate material
 $C \leq 0.25\%$ for forgings and castings
2. Carbon equivalent $Ceq\% \leq 0.45\%$ based on the formula:

$$Ceq\% = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

3. For fine grained steels the sum of V + Ti + Nb shall be kept below 0.15% in order to avoid unacceptable deterioration of toughness in the h.a.z..

If the values are above the requirements listed, the more precautions need to be taken. The main problems are hardening in the weld metal and h.a.z. with a high risk of hydrogen cold cracking.

Increased preheat temperature and an increased heat input could avoid an unacceptable hardening of the weld metal and h.a.z.. Cooling rate is also of critical importance to the mechanical properties of the weld and h.a.z..

Carbon steels with UTS ≤ 450 N/mm²

These steels have a good weldability, since the requirements for C and Ceq are normally achieved.

Under most circumstances, no special precautions are required for welding. If using m.m.a., suitable electrodes are rutile, cellulosic or basic low-hydrogen types; basic

NOTES

low-hydrogen electrodes would normally be applied for wall thicknesses above approximately 25 mm.

Carbon and carbon-manganese steels with UTS > 450 N/mm²

The C and Ceq requirements are often not met, therefore special precautions should be taken to avoid unacceptable hardening and hydrogen cold cracking.

If using m.m.a., basic low-hydrogen electrodes with matching mechanical properties would normally be used. Preheating between 100°C and 150°C, plus a p.w.h.t. may be required to reduce the hardness and to restore the ductility in the h.a.z..

Fine-grained C-Mn steels with UTS > 450 N/mm²

These steels have improved impact properties. The C and Ceq requirements are normally achieved, therefore a p.w.h.t. is not normally required. However, for certain applications a p.w.h.t. is required, since the maximum hardness requirement may be exceeded in the h.a.z..

For the higher yield strength steels precautions are required to avoid hydrogen cold cracking and hardening. Preheating may be required between 100°C and 150°C for wall thicknesses above 25 mm, and low hydrogen consumables with matching mechanical properties should be used.

Fine-grained micro-alloyed and low Ni-alloy steels.

Fine-grained (*killed*) steels and low Ni-alloy steels, including 3.5% Ni, are used for low-temperature applications; both are readily weldable.

For fine-grained steels the C and Ceq requirements are generally met.

The heat input/plate thickness ratio and cooling time are important to achieve satisfactory ductility in the h.a.z..

Fine-grained steels with UTS ≤ 450 N/mm²

Preheating is not often required below 25 mm.

Hardening in the h.a.z. and cold cracking should not occur, since the cooling time between a temperature drop (*t*) from 800-500°C (typical governing parameter) exceeds 5 seconds for most welding conditions. A maximum cooling time may be quoted to control impact properties.

Fine-grained steels with UTS > 450 N/mm²

Preheat at 100-150°C is typically required for wall thicknesses above 25 mm.

The welding conditions should ensure that the cooling time between 800-500°C is over 10 seconds to prevent hardening and the risk of cold cracking in the h.a.z.. A maximum cooling time may be quoted to control impact properties.

The yield strength of the high-strength fine-grained steels with UTS > 450 N/mm² could be reduced by p.w.h.t.. Therefore if a p.w.h.t. is considered necessary, e.g. for low-temperature applications and for wall thicknesses above 35 mm, the p.w.h.t. temperature may be as low as 540-580°C.

Low Ni-alloy steels (including 3.5 Ni)

Matching low-hydrogen types of consumables should be used for welding. 3.5 Ni steels should be welded with 2.5 Ni consumables because a higher Ni content in the weld metal could cause hot cracking; preheating is normally not required.

P.w.h.t. of 3.5 Ni steels may be required for low-temperature applications. P.w.h.t. at 570-590°C is typically required for wall thicknesses above 50 mm. Temperatures above 650°C are critical for 3.5 Ni steels, since these will severely decrease the ductility.

NOTES

0.3 and 0.5 molybdenum steels

Steels with 0.3% and 0.5% Mo are used for high-temperature service.

The weldability of 0.3-0.5% Mo steels depends on the C content and the Ceq. A specification may state:

"For $C_{eq} \leq 0.45$ no precautions are required. The steels are readily weldable and p.w.h.t. is required only for wall thicknesses above 20 mm.

For $C_{eq} > 0.45$ preheating is required for all wall thicknesses.

P.w.h.t. is also required when hardening of weld metal or h.a.z. occurs."

0.3% Mo steel

0.3% Mo steel is mainly used for temperatures up to 500°C. Its choice is based on its improved creep strength.

0.3% Mo are typically welded with low hydrogen consumables depositing 0.5% Mo. For wall thicknesses below 20 mm preheating is not usually required; above 20 mm preheating to 100-150°C is recommended. P.w.h.t. may be required.

0.5% Mo steel

0.5% Mo steel is used for high temperature service up to 500°C and also for hydrogen service.

0.5% Mo should be welded with matching, low-hydrogen depositing consumables. For wall thicknesses below 20 mm preheating is not usually required. Above 20 mm preheating to 100-150°C is recommended.

For hydrogen service, cooling rates after welding should be carefully controlled and p.w.h.t. would normally be carried out irrespective of wall thickness. For high temperature service p.w.h.t. may be required.

Low-alloy chromium-molybdenum steels

Cr-Mo steels are used for their enhanced strength at elevated temperatures and for resistance to hydrogen attack and corrosion by sulphur-bearing hydrocarbons.

The steels are delivered either in the annealed, normalized and tempered, or quenched and tempered condition.

The weldability is related to the carbon content, i.e. the higher the C-content the more precautions shall be taken to avoid hydrogen cracking.

Preheating, interpass temperature, post-heating and p.w.h.t. should be adequately controlled. A specification may state:

"For thicknesses < 10 mm the cooling from preheating to ambient temperature shall be done under an insulating cover. For thicknesses between 10 and 30 mm post-heating shall be applied after welding, prior to cooling to ambient temperature, unless a p.w.h.t. is carried out immediately.

For sections above 30 mm an intermediate p.w.h.t. at 600-620°C shall be carried out immediately after welding without cooling down to the ambient temperature.

Final p.w.h.t. shall always be carried out in accordance with Table X irrespective of wall thickness.

Intermediate and final p.w.h.t. should be done in a furnace or electrically. P.w.h.t. by means of flame torches is not allowed."

1Cr-½Mo and 1¼Cr-½Mo Steels

1Cr-½Mo is used for high-temperature service up to 600°C on the bases of its good creep strength. This steel may also be used for hydrogen service provided that the Cr content is at least 1%.

Only low hydrogen matching chemical composition weld metal should be used.

1Cr-½Mo is susceptible to cracking caused by hydrogen or microstructure brittleness and preheating between 100-150°C should be applied.

NOTES

To minimize air hardening after welding, cooling down to ambient temperature should be done under insulation.

2½Cr-1Mo

2½Cr-1Mo is used for hydrogen service and temperatures up to 625°C.

Extreme care should be taken when welding is carried out, since it is highly susceptible to cracking.

Only low hydrogen matching chemical composition weld metal should be used. A specification may state:

"For hot hydrogen service alloy additions to weld metal shall take place only via the filler wire; alloy addition through flux or coating is not permitted.

The weld metal shall be checked, prior to use, for the minimum specified amounts of Cr and Mo."

Preheating would typically be carried out at a minimum of 200°C regardless of wall thickness.

Interpass temperature should not drop below 150-200°C during welding.

5Cr-½Mo and 9Cr-1Mo

Both steels are used for service temperatures up to 650°C and for resistance to sulphur corrosion.

Low-hydrogen consumables with matching chemical composition should be used for welding.

5Cr-½Mo and 9Cr-1Mo, like other Cr-Mo steels, are susceptible to cracking by either hydrogen or microstructure brittleness but to a lesser extent than 2½Cr-1Mo.

Due to the higher Cr amount these steels are more susceptible to air-hardening. The preheat temperature would typically be 200-250°C and cooling down to ambient temperature should be done under insulation.

Stainless Steels

Stainless steels (SS) are Fe-based alloys that contain at least 12% Cr for corrosion resistance. However, the majority of the stainless steels have a higher Cr content and also Ni and Mo as main alloying elements.

Based on the microstructure, stainless steels can be divided into four groups:

- martensitic SS
- ferritic SS
- austenitic SS
- duplex (austenitic/ferritic) SS

Austenitic SS is the most important group.

Stainless steels can also be divided, based on their application, into:

- corrosion-resistant SS
- creep and oxidation-resistant SS
- low-temperature-resistant SS

Consequently the rules for welding of stainless steels depend not only on the microstructure, but also on the required application.

Martensitic and ferritic stainless steel

Martensitic and ferritic stainless steels are not generally used as material for welded constructions, since they often give problems during fabrication, welding and heat treatment.

Examples of applications are the strip lining or cladding of pressure vessels to resist sulphur corrosion, internals of valves and castings for pumps.

NOTES

The main problem with the welding of martensitic and ferritic SS is the formation of hydrogen induced cold cracking in the weld metal and/or h.a.z.; this is caused by the formation of martensite with high hardness.

With martensitic SS, the martensite formation is in the whole weld zone and can be measured.

With ferritic SS, the martensite formation is only along the grain boundaries and a hardness increase can hardly be measured.

Therefore martensitic/ferritic SS are in most cases welded with an austenitic type of weld metal. The martensite formation is then restricted to the h.a.z.. The hardness of the martensite in the h.a.z. can be reduced by selecting a material with a lower carbon content.

To prevent cold cracking in the h.a.z. for thick sections, the same measures are taken as for welding Cr-Mo steels, i.e.:

- a. preheating to 200-250°C,
- b. welding preferably with low-hydrogen types of matching consumables,
- c. maintaining the interpass temperature at 200-300°C for heavy sections during the welding operation,
- d. post-heating at 200-250°C, cooling to 100°C immediately followed by a heat treatment at 700-790°C to change the martensite into carbides and ferrites.

The ductility of the ferritic SS in the h.a.z. may be poor, due to grain growth and/or formation of carbon-nitrides.

Annealing heat treatment at 905-1050°C and furnace cooling will often improve the ductility to an acceptable level.

Austenitic stainless steel

The austenitic stainless steels are usually used for welded constructions. The major favourable considerations are the combination of ease of fabrication and welding, together with suitability for corrosion, low-temperature and high-temperature service.

The selection of the welding consumables depends on the type of austenitic SS and the intended service. To prevent any problems during fabrication/heat treatment/welding and service, the following rules should be complied with:

- a. Tack welds have to be made at small intervals.
- b. Heat input per weld run should be low to avoid too high an interpass temperature and overheating of the weld area.
- c. Cleanliness is very important, special attention shall be paid to the weld area to avoid carbon pick-up, hardening and hot cracking.
- d. For m.i.g. or t.i.g. welding, backing gas should be applied to prevent oxidation of the h.a.z. and weld.
- e. After heavy oxidation of the weld and h.a.z. the corrosion resistance can be restored by passivation treatment.
- f. For most applications a weld consumable is used with a low susceptibility to hot cracking in the weld metal, e.g. a weld metal with about 10% ferrite.
- g. To prevent sensitization and weld decay at the grain boundaries, the carbon content for corrosive service is kept below 0.08%C or the weld metal is stabilized with Nb.

Welding of austenitic/ferritic SS

Austenitic/ferritic stainless steels, also referred to as *duplex SS*, contain about 50% ferrite and 50% austenite. These steels exhibit a high strength and better corrosion resistance in chloride environments than the austenitic SS. Their ductility and toughness tend to be lower than that of the austenite SS.

The main welding problem is producing weld metal with a similar amount of ferrite/austenite as in the base metal. This can be achieved with the use of welding consumables with a similar chemical composition to that of the base metal.

NOTES

Nickel and nickel alloys

Nickel and nickel alloys are used for their special corrosion resistance and their good mechanical properties at elevated temperatures.

Nickel and nickel alloys are selected based on their ability:

- to resist electrochemical corrosion and/or stress corrosion;
- to resist chemical corrosion, also at elevated temperatures;
- to resist severe creep conditions in combination with oxidation and corrosion.

The rules for welding nickel and nickel alloys depend not only on the chemical composition but also on the required application.

The area adjacent to the weld preparation should be extremely clean to avoid hot cracking. S, Pb, Sb, Cd and Zn are detrimental impurities, which may be present in grease, paint, etc. Acetone or equivalent solvents are used for cleaning. The oxide layer should be removed by grinding to a metal bright surface appearance just prior to welding, to avoid porosity.

Weld preparations are recommended which are more open than normal, to minimize the risk of lack of fusion defects due to the low fluidity of the weld metal.

Cold heavily deformed weld edges are prone to hot cracking or *ductility dip cracking*. Therefore, Ni and Ni alloys should be ordered in the annealed or hot rolled condition.

For m.i.g. or t.i.g. welding, only commercially pure argon or a mixture of argon and 5-10% hydrogen shall be used.

Care should be taken to prevent oxidation of the filler wire tip during welding; the wire tip should remain in the protecting gas and be removed only after it is completely cooled down. If the wire tip is oxidized it should be cut off. The welding consumables contain de-oxidizers such as Ti to prevent porosity in the weld metal.

The weld bead is normally ground smooth before the next weld bead is made, to minimize hot cracking especially at the stop/start positions.

Pure nickel

Two types of commercial pure nickel are available; one with a carbon content below 0.15%C and one with a carbon content below 0.02%C. Examples of trade names are nickel 200 and 201.

For temperatures below 300°C both grades may be used. Low-carbon grade nickel should be used for service temperatures above 300°C.

Pure nickel welding consumables should be used when welding for service temperatures below 300°C. For matching chemical composition preference is given to a low carbon and a low Ti content.

When welding for service temperatures above 300°C, the welding consumables should have the low carbon grade and a low Ti content.

For chlorine service at temperatures above 450°C the weld metal containing Ti may be attacked. In this case a low-carbon type Ni wire without Ti shall be applied to prevent the selective attack. The porosity of the weld metal can be minimized by extreme cleaning of the weld area.

Ni-Fe-Cr

Examples of trade names are Incoloy 800 and 800H. The nickel content is about 35%. This material is applied for certain corrosive environments, often in combination with good mechanical properties at elevated temperatures.

For temperatures, e.g. below 575°C, the grade Incoloy 800 may be used; for temperatures, e.g. above 575°C, the grade Incoloy 800H may be used.

In general the alloys are welded with consumables of the type 70% Ni-Cr-Fe, e.g. Inconel 182 (82), Incoweld A; they should not be welded with Ni-Cu (Monel) consumables, this is to avoid hot cracking.

NOTES

Welding consumables with the similar chemical composition as the base material are generally susceptible to hot cracking.

Ni-Fe-Cr-Mo

Example of a trade name is Incoloy 825; the nickel content is about 40%. This material is applied for corrosive environments and for resistance to chloride stress corrosion cracking.

Two types of welding consumables are suitable: the 70% Ni-Cr-Fe-Mo and a matching type 40% Ni-Cr-Fe-Mo.

The matching type is more prone to hot cracking in the weld metal, especially at high heat inputs.

Ni-Cr-Fe and Ni-Cr-Fe-Mo alloys

Examples of trade names are Inconel 600 and 625. This material is applied for corrosive environments in combination with good mechanical properties at elevated temperatures.

Welding consumables of matching chemical composition should be used.

Ni-Cr-Mo alloys

Examples of trade names are Hastelloy C, C-276, C-4; the nickel content is about 55%. This material is applied for severe corrosive conditions.

The normal type, i.e. Hastelloy C, is susceptible to weld decay and a heat treatment after welding is required. Exposure at temperatures above 500°C will cause carbide precipitation, a loss of corrosion resistance and some loss of ductility.

The low-carbon grade, Hastelloy C-276, is not susceptible to weld decay in normal welding conditions. Prolonged exposure at elevated temperatures will cause carbide precipitation and loss of corrosive resistance.

The very low carbon grade, Hastelloy C-4, is not susceptible to weld decay. Exposure at elevated temperatures will hardly cause carbide precipitation and/or a loss of ductility.

The Ni-Cr-Mo alloys shall be welded with consumables of matching chemical composition, in most cases provided by the plate material manufacturer. Carbon and sulphur pick-up from the weld area shall be avoided by careful cleaning.

Ni-Mo alloys

Examples of trade names are Hastelloy B and B-2; the nickel content is about 65%. This material is applied for severe corrosive conditions.

The normal type, i.e. Hastelloy B, is susceptible to weld decay. Hence heat treatment after welding is required.

The very low carbon grade, e.g. Hastelloy B-2, is not susceptible to weld decay. Both grades are susceptible to embrittlement by the formation of intermetallic Ni-Mo compounds at prolonged exposure above 500°C.

The alloys are also susceptible to ductility dip cracking. A special annealing heat treatment is required to restore the ductility.

The alloys shall be welded with very low carbon consumables with matching chemical composition. Carbon and sulphur pick-up from the weld area shall be avoided by careful cleaning.

Ni-Cu

Examples of trade names are Monel 400 and Monel K500.

Monel K500 is a precipitation hardening alloy for corrosive conditions with improved strength. It is used for shafts and other parts which are not to be welded.

The normal Ni-Cu alloy is readily weldable; consumables with matching chemical composition should be used.

P.w.h.t. may be required for corrosive conditions.

NOTES

Stress

Stress may be divided into two main categories: *normal stress* and *shear stress*.

Normal stress is stress arising from a force applied perpendicular to a cross-sectional area of a material:

- **tensile stress** - normal stress resulting from tension,
- **compressive stress** - normal stress resulting from compression.

Shear stress - is stress arising from forces which are parallel to, and lie in, the plane of the cross-sectional area, e.g. stress resulting whilst tightening a screw.

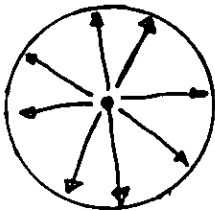
If we apply weld metal onto a material or between two pieces of material which are being joined, the surrounding areas will expand and contract (distort) in various regions of the weld and parent material. When the weld cools these varying forces may change direction, but some will remain within the material, these are called *residual stresses*. Residual stresses are self balancing internal forces and not stresses induced whilst applying an external load.

The stress acting circumferentially around a pipe to internal pressure is termed *hoop stress*.

Stresses are more concentrated at the surface of a component, therefore surface breaking defects tends to be more critical than sub-surface defects.

The removal of residual stresses is termed *stress relieving*.

Hoop Stress



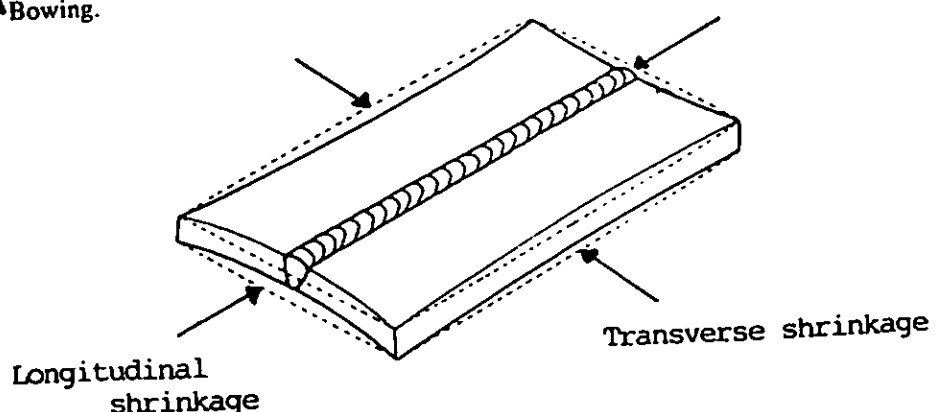
Distortion

Distortion caused through welding is the change of shape of at least one of the components being welded. This change in shape may be temporary or permanent. Distortion is caused by stress.

Distortion will occur if two pieces of plate material, which are to be joined, are free to move during welding. If the two pieces of plate material are not free to move, i.e. restrained, the forces will remain as residual stresses.

Types of distortion

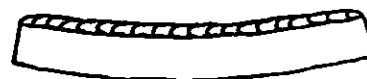
- Longitudinal shrinkage.
- Transverse shrinkage.
- Angular distortion.
- Bowing.



NOTES



Angular distortion



Bowing

Factors which affect distortion

- Material properties and condition.
- Heat input.
- Lack of restraint.
- Amount of weld metal deposited.

Methods of reducing distortion

- Preheating. - allows distortion
- Forced restraint. - stiffeners
- Use a balancing welding technique, e.g. back skip welding or back step welding.
- Use a different joint design to reduce the amount of weld deposited.
- Reduce the heat input. - Single pass welds only.

NOTES

Post-heat treatment in this context is a process in which metal in the solid state is subjected to one or more controlled heating cycles after welding. The post heat treatment of welds (p.w.h.t.) is normally carried out for the purpose of *stress relief*, i.e. the reduction of localised residual stresses.. Post-heat treatment may also be used to produce certain properties, such as:

- softening after cold working;
- hardening to produce improved strength and hardness, this may be very hard and brittle;
- tempering to improve hardened structures giving ranges of strength with toughness.

The relevant variables for a p.w.h.t. process which must be carefully controlled are as follows:

- heating rate,
- temperature attained,
- time at the attained temperature,
- cooling rate - in certain circumstances.

Note: Any temperatures quoted in the following sub-sections apply to C-Mn steels. Temperatures may differ for other steels.

Stress relieving

Used to relax welding stresses without any significant affects on the components metallurgical structure because austenite is not produced.

Stress relief is achieved by heating to 550-650°C, holding for the required time, e.g. 1 hour per 25 mm thickness, and then cooling down in air. Local heating is carried out with gas flame or electric elements; whole components may be stress relieved in a furnace.

Annealing

Full anneal - is used to produce a very soft, low hardness material suitable for machining or extensive cold working. A full anneal is achieved by very slow cooling after the steel has been heated to above 910°C and made fully austenitic. By the time the steel has been very slowly cooled down to 700°C, all the austenite changes to ferrite and pearlite with extensive grain growth. The component is cooled down in air from 680°C.

Sub-critical anneal - this process is also known as *spheroidizing* and is used to produce a soft, low hardness steel—cheaper than full anneal. Temperatures must not rise above 700°C. A sub-critical anneal is achieved by heating to 680-700°C, holding for sufficient time for full recrystallisation to occur, i.e. new ferrite grains to form; the component is then air cooled in most circumstances.

Normalising

Normalising is used to maintain and improve mechanical properties and to modify grain structures by making them more uniform giving a refined structure avoiding grain growth.

NOTES

Normalising is achieved by heating the steel until it is fully austenitic—the same temperature as that used for full anneal—soaking for the minimum time necessary to achieve a uniform through thickness temperature and then air cooling.

Hardening/quenching

Hardening is achieved by very fast cooling from the austenite region.

The steel is first heated to produce austenite; it is then allowed to soak at this temperature to produce grain uniformity, and then fast cooled by quenching into oil or water (brine) to achieve the desired hardness.

After quenching, the steel is highly stressed, very hard and brittle with a high tensile strength. Quenched steel is very prone to cracking and therefore requires tempering.

Tempering

Tempering is used to produce a range of desired mechanical properties to meet specific requirements.

Tempering is achieved by slowly heating the hardened steel to a temperature between 200-650°C to produce the required tensile strength and toughness properties; the component may then be air cooled.

At 200°C the quenching stresses are reduced and the steel will give maximum tensile and hardness with a reduced risk of cracking.

Increasing the tempering temperature reduces the hardness and tensile strength whilst increasing the toughness and ductility. At 650°C, a full temper is produced, giving a very fine grained soft steel with a spheroidized structure.

Hydrogen release

Both normalising and annealing heat treatment processes will help to release hydrogen from a weld area. However, there may be a situation where only hydrogen release is required. This may be performed by heating the weld area to 150-200°C and soaking for approximately 10-24 hours.

NOTES

Welding Procedures

BS EN 288 : Specification and approval of welding procedures for metallic materials.

10 Prior to the start of welding production on contract work, detailed written *welding procedures* or *welding procedure specifications* are submitted by the contractor to the client for content approval, or alternatively, the welding procedures may be provided by the client for the contractor to work in accordance with.

20 A welding procedure shows all the variables involved with the production welding, e.g. welding process, technique, consumable type, material, preheat etc.

Once the content of a written procedure has been approved, a weld is made in accordance with the requirements of that procedure-this is known as a *welding procedure test (w.p.t.)* or a *welding procedure qualification test*. The weld is inspected and tested to ensure that all the welding variables used are compatible and can produce a sound weld satisfying the NDT and mechanical requirements of the relevant specification.

30 A welding procedure test also sets a standard which welders must comply with; a prime duty of the welding inspector is to ensure that this is the case. A welding inspector should be present throughout a welding procedure test to ensure the written procedure is being strictly adhered to.

Welding variables

40 The following list shows the variables which are likely to be encountered on welding procedures:

- a. Welding process.
- b. Joint design.
- 50 c. Welding position.
- d. Joint cleaning, jiggling and tack welding.
- e. Welding technique.
- f. Back gouging.
- g. Backing.
- h. Filler metal classification, manufacture, trade name and dimensions.
- 60 i. Filler metal and flux drying procedure.
- j. Electrical parameters - current type, amperage, voltage, polarity (d.c.)
- k. Travel speed and wire feed speed (mechanized welding).
- l. Preheat temperature.
- m. Interpass temperature
- n. Post weld heat treatment.
- 70 o. Other variables specific to the welding process, e.g. flux type for submerged arc welding; shielding gas and gas flow rate for gas shielded processes.

80 A contractor must submit a new written welding procedure before any welding variables are changed in production. The specification (or client) will govern whether a new procedure weld needs to be made-this will depend on whether the proposed change is an *essential* or *non-essential* variable.

EXAMPLE 1

90 A welding procedure test for m.m.a. welding, using basic electrodes, has been qualified. During production the contractor wishes to use rutile electrodes instead.

In this situation, the contractor would almost certainly have to re-submit and re-qualify a new procedure, even if the specification permitted the use of rutile electrodes on this type of weld, i.e. changing the type of flux coating is changing an essential variable.

NOTES

EXAMPLE 2

A welding procedure test for m.m.a. welding on a large diameter pipeline using two root bead welders has been qualified. During production the contractor wishes to raise the number of root bead welders to three.

In this situation, the contractor would not normally need to qualify a new procedure providing a written procedure has been submitted and approved—this is a non-essential variable. However this would not be the case vice versa, i.e. three root bead welders down to two—this is an essential variable.

Ideally, procedure welds should be made under conditions which simulate production stress, however, this not always done due to practical constraints.

Inspection of w.p.t. welds

When a procedure weld has reached ambient temperature—or when otherwise specified—it undergoes examination by NDT and destructive testing.

It is common practice for the welding inspector to mark up the areas on the weld which require the removal of test coupons for mechanical testing. These test areas are normally specified in the applicable specification.

Welder tests

General

A welders test—also known as a welder qualification test (w.q.t.), or welder approval test—is carried out to ensure the welder is able to produce a sound weld that meets the requirements of the relevant welding procedure and application specification.

A welder who makes a procedure test weld would automatically qualify when the welding procedure test qualifies.

Welding variables

The variables used in a welders qualification test may not always be exactly as those used in the welding procedure test. The limitation of variables may also differ between specifications.

The following variables, if changed within specified limitations, may not necessarily cause a new welder qualification test to be made:

- a. parent material type,
- b. consumable or shielding gas type,
- c. dimensions of parent material,
- d. welding position,
- e. type of joint,
- f. preheat temperature,
- g. post-weld heat treatment procedure.

Basically speaking, if a variable changes, and this new variable is considered more difficult to use, then a new qualification test weld would normally be made.

A welding procedure test proves the weld/welding; a welder qualification test proves the welders ability to weld in accordance with the procedure

If a change was proposed outside a specified limitation, a new welder qualification test would have to be made, because this would be a change of an essential variable.

NOTES

The following table is an extract from a typical specification which details welder approval. It shows limitations for the position variable.

Welder approval				
Approval test		Position and type of weld approval		
		Plate		Pipe
Weld	Position	Groove or cavity	Fillet weld	Groove weld
Plate: groove or gouged cavity	1G	1G	1F	1G
	2G	1G 2G	1F 2F	1G 2G
	3G	1G 3G	1F 2F 3F	1G
	4G	1G 4G	1F 2F 4F	1G
	3G and 4G	1G 3G 4G	All	1G
Plate: fillet	1F	-	1F	-
	2F	-	1F 2F	-
	3F	-	1F 2F 3F	-
	4F	-	1F 2F 4F	-
	3F and 4F	-	All	-
Pipe: groove	1G	1G	1F	1G
	2G	1G 2G	1F 2F	1G 2G
	5G	1G 3G 4G	1F 2F 3F 4F	1G 5G
	6G	All	All	All
	2G and 5G	All	All	All

Inspection of w.q.t. welds

It is usually necessary for a welding inspector to be present throughout a welders qualification test to ensure that the welding is being carried out in accordance with the approved procedure and specification.

A welding inspector may stop a test before completion if it is obvious the welder has failed, e.g. due to an excessive amount of lack of root penetration, other obvious defects, or excessive time taken.

In normal circumstances only one test weld is permitted, however, if a failure is due to conditions beyond the control of the welder, e.g. because of a faulty welding set, then the welder should be allowed a re-test.

Defect acceptance tolerances for welder approval may be more strict than those for the production welds-this is not always the case and again is dependant upon the specification.

On welder qualification test welds, it is not normal, or necessary, to carry out destructive tests which measure mechanical properties, such as tensile strength or toughness, if a welder is welding in accordance with the procedure which has passed mechanical testing there is no point. Therefore, it is usual for specifications to request visual examination and NDT only for these welds.

Visual examination and NDT do not necessarily reveal all defects, especially when they are very small, or when they lie in a different plane to that which the NDT method applied will detect. This problem results in some specifications requesting bend tests, macro tests, nick-break tests, or a combination of them, instead of, or in addition to, NDT. These destructive tests assess the general soundness of the weld.

NOTES

BS 709 - *Methods of destructive testing fusion welded joints and weld metal in steel.*
Mechanical testing of welded joints may be carried out for the following reasons:

- welding procedure approval.
- welder approval,
- production quality approval.

A welding consumable manufacturer will carry out *all-weld metal tests* for each consumable type they manufacture. The parent material is normally subjected to extensive testing prior to its acceptance by a client and subsequent use on a contract. However, separate testing is still required for a welded joint, because it usually consists of three metallurgically different areas which interrelate: the weld, h.a.z., and parent material.

Mechanical testing is a destructive procedure and is not usually carried out on any component required for use, therefore representative test samples produced under similar conditions to the in-service components are normally used and comparisons made. Methods used include welding procedure tests, random sampling of mass produced items and/or run-on - run-off plates.

The tests most frequently used to assess the properties of welded joints are:

- tensile, - finds *U_{ts}*, and elongation, yield point.
- bend, - opens weaknesses, ductility assesment.
- nick-break, - general weld soundness.
- impact. - 2 types:- Charpy, Izod, :- Notch toughness & fracture surg assesme
- hardness, - Indication of weldability.
- macroscopic/microscopic. - visual.
- CTOD.

Many standard specifications exist for mechanical testing. If the standard specification is exclusive to a particular mechanical test, it should be noted that the content will detail the equipment to use, how to carry out the test and report the test results, but the acceptance criteria would be specified elsewhere, e.g. in the application specification.

Tensile test

BS EN 10 002 - *Tensile testing of metallic materials*

BS EN 10 002-1 - *Method of test at ambient temperature*

Purpose of test

A *tensile* test applies stress in the opposite direction to a test which applies compressive stress, i.e. a tensile test puts the test item in tension and attempts to pull it apart.

A tensile test can be used to assess the following:

- the *yield point* of the specimen - the point at which the specimen undergoes plastic deformation;
- the *ultimate tensile strength (u.t.s.)* of the specimen - the maximum load a specimen can withstand;
- the *ductility* of the specimen - expressed as % elongation.

There are different types of tensile tests for welds; these include:

- the *transverse tensile test* - used on joints containing butt welds;
- the *all-weld tensile test* - used to test either the filler material properties, or the quality of the deposited weld metal as a whole;

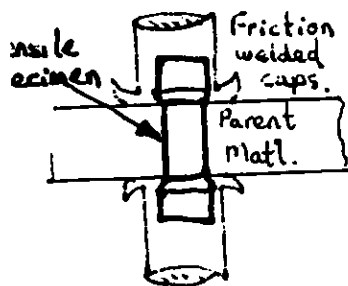
atic :- Resistance to a steadily applied load.

anic :- Resistance to a suddenly applied load.

NOTES

Cruciform :- Not often carried out due to fillet weld not often in tension.

Short tensile :- From BS 5135 so a through thickness test.



Assessment of through thickness Ductility. How is it prone to Lamellar tearing.

- the *cruciform test*, - used to test the relative tensile strength of fillet weld joints between plates.

Preparation of specimen

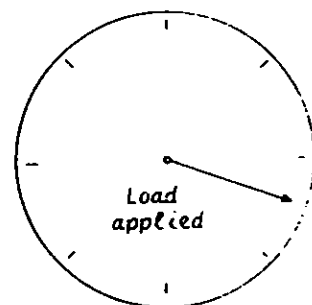
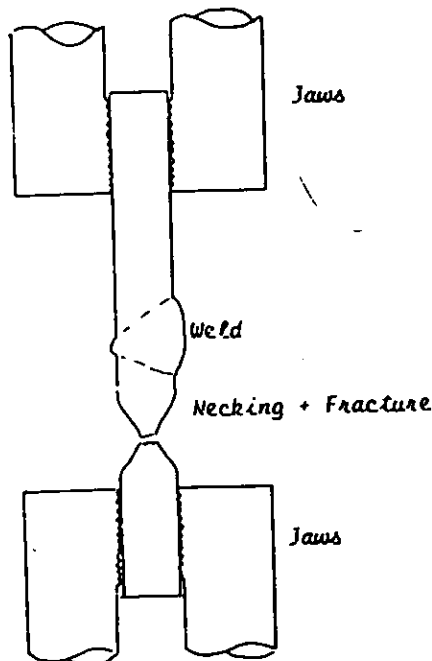
Test specimens are cut from designated areas of the welded assembly, the length and width, method of cutting (thermal or machine), and requirements for the removal or leaving of the weld reinforcement would be stated in the appropriate specification. The edges should be made smooth—normally filed—and any corners in the test area radiused slightly to reduce stress raisers.

On an *all-weld tensile test*, it is a common requirement to test for the elongation percentage. In this case, two punch marks would be applied in line with the applied stress. The distance between the punch marks, which would be specified, is called the *gauge length*. typically 50mm.

Test procedure

Two sets of vice jaws are used to clamp the test specimen at the top and bottom; hydraulic power is then applied to force the specimen apart. A dial, usually calibrated in pounds, tonnes or newtons, records the load applied. As the load increases, the dial registers the amount until fracture occurs.

For a transverse tensile test made on C or C-Mn steel welds, fracture usually occurs in the parent material. A specimen which snaps in the weld region is usually acceptable providing the specification requirements are met.



Newton's
or
Pounds
or
Tonnes

In all cases *necking* of the steel specimen prior to fracture should occur: the reduction in cross-sectional area indicates a ductile fracture. Steel specimens which snap and do not exhibit any *necking* are usually cause for rejection.

Calculations for ultimate tensile strength

The u.t.s. can be calculated by dividing the maximum load applied by the least cross-sectional area (c.s.a.) of the test specimen. The maximum load applied is obtained from the dial on the machine; the least cross-sectional area is measured prior to testing with a micrometer.

NOTES

$$U.t.s. = \frac{\text{maximum load applied}}{\text{least c.s.a.}}$$

EXAMPLE 1

What is the u.t.s. if a tensile test specimen had a least c.s.a. of 1.015" x 0.627" and the maximum load applied was 46,000 lbs?

a. $U.t.s. = \frac{\text{maximum load applied}}{\text{least c.s.a.}}$

b. $U.t.s. = \frac{46,000 \text{ lbs}}{1.015" \times 0.627"}$

c. $U.t.s. = \frac{46,000 \text{ lbs}}{0.636 \text{ in}^2}$

d. $U.t.s. = 72,327 \text{ p.s.i.}$

EXAMPLE 2

What is the u.t.s. if a tensile test specimen had a least c.s.a. of 25.20 mm x 17.52 mm and the maximum load applied was 235 kN?

a. $U.t.s. = \frac{\text{maximum load applied}}{\text{least c.s.a.}}$

b. $U.t.s. = \frac{235,000 \text{ N}}{25.20 \text{ mm} \times 17.52 \text{ mm}}$

c. $U.t.s. = \frac{235,000 \text{ N}}{441.5 \text{ mm}^2}$

d. $U.t.s. = 532.3 \text{ N/mm}^2$

Calculations for elongation

The % elongation can be calculated by:

$$\text{Strain \%} = \frac{\text{Increase of gauge length} \times 100}{\text{Original gauge length}}$$

EXAMPLE

A tensile test piece had an original gauge length of 50 mm; after testing this had increased to 62.5 mm. What is the percentage elongation?

a. $\text{Strain \%} = \frac{\text{Increase of gauge length} \times 100}{\text{Original gauge length}}$

b. $\text{Strain \%} = \frac{12.5 \text{ mm} \times 100}{50 \text{ mm}}$

c. $\text{Strain \%} = 25\%$

144.9 p.s.i. = 1 N/mm²

1 N/mm² = 1 MPa.

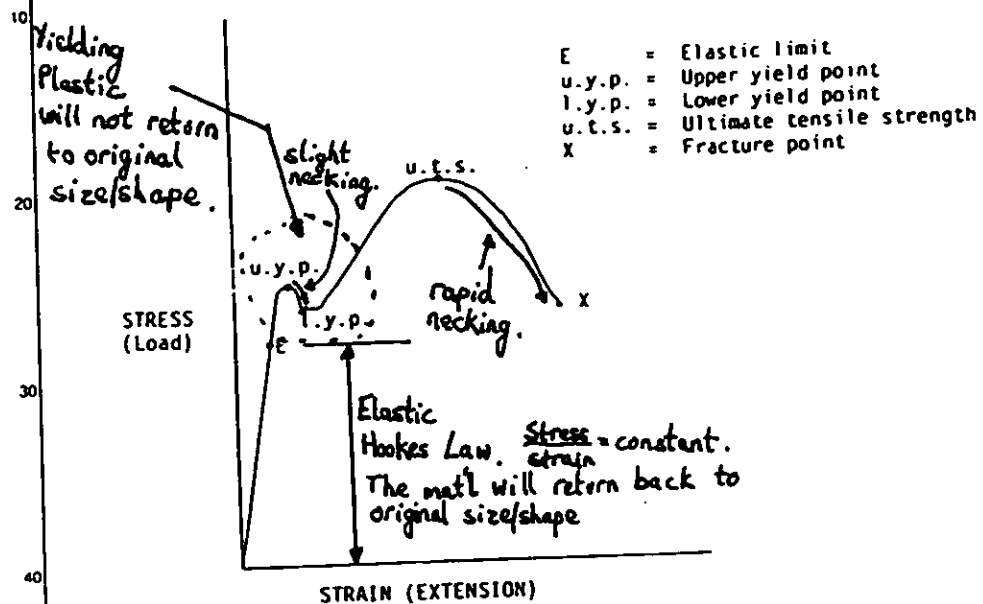
$(T) = 10^{12}$
 $(G) = 10^9$
 $(M) = 10^6$
 $(K) = 10^3$
 $(m) = 10^{-3}$
 $(\mu) = 10^{-6}$
 $(n) = 10^{-9}$

al min elongation for steels :- 18-24%

NOTES

Stress-strain relationship

The relationship between stress and strain can be plotted on a graph to produce a *stress-strain curve*. The following example shows a curve for a low carbon steel.



Strain (extension) is the result of stress (load applied). therefore as the load is applied the test piece will begin to extend.

If the load is removed at any point up to the *elastic limit (E)*, the specimen will behave elastically and return to its original length. Beyond the elastic limit the *upper yield point (u.y.p.)* is reached, this is where the material *yields* and *plastic deformation* occurs. At this point there is a noticeable drop in the applied load until the *lower yield point (l.y.p.)* is reached. Beyond the lower yield point, the load begins to increase again.

Yielding is the slipping of the atomic structure; it commences at the upper yield point and stops at the lower yield point. Yielding stops because the slipping action *cold works* the steel and increases the tensile strength.

After yielding, the load increases to the point of ultimate tensile strength (u.t.s.), this is the maximum load the specimen can withstand, it is not the point of fracture. Beyond the u.t.s. the specimen *necks* locally; this leaves a high load acting on the reduced cross-sectional area, therefore fracture at X rapidly follows.

NOTES

Bend test

Purpose of test

Bend tests are carried out on butt welds to determine the soundness of the weld zone. The commonly applied bend test is the *transverse bend test* where the specimen is cut so that the weld is transverse to the specimen length. There are three ways to perform this type of bend test on a single sided weld:

1. The *root bend test* puts the root in tension. Main aim is to open up and enlarge surface breaking discontinuities.
2. The *face bend test* puts the face in tension. Main aim is to open up and enlarge surface breaking discontinuities.
3. The *side bend test* puts the side of the weld in tension. Main aim is to open up and enlarge sub-surface discontinuities.

A *longitudinal bend test*, as the name suggests, has the weld longitudinal to the specimen length. The inner or the outer reinforcement may be placed in tension depending on specification requirements.

Bend tests may also be used to give an assessment of the weld zones ductility.

Test specimens

Bend test specimens are cut from designated areas of the welded assembly, the length and width, method of cutting (thermal or machine), and requirements for either removing or leaving of the weld reinforcement would be stated in the appropriate specification.

For all types of bend test, the specimen width is usually at least $1.5 \times$ the thickness and the weld reinforcement is usually dressed flush on both sides. The edges of the specimen are rounded off - normally to a maximum 10% radius.

Equipment and test procedure

Bend testing may be carried out by two methods:

- by using a hydraulically operated former to bend each test specimen through the centre of a pair of supports. The test specimen is placed on the supports, the centre point of the former brought into contact with the centre of the weld. Pressure is then applied to bend the specimen usually through to 90° 135° or 180° as specified.

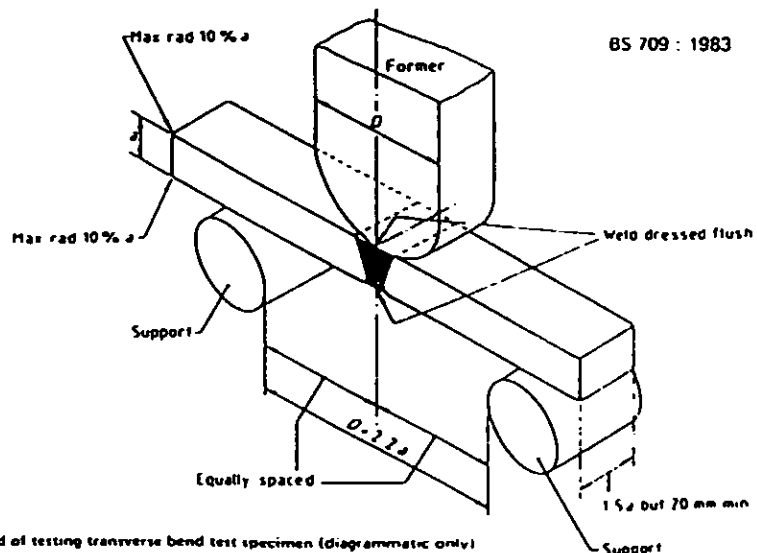
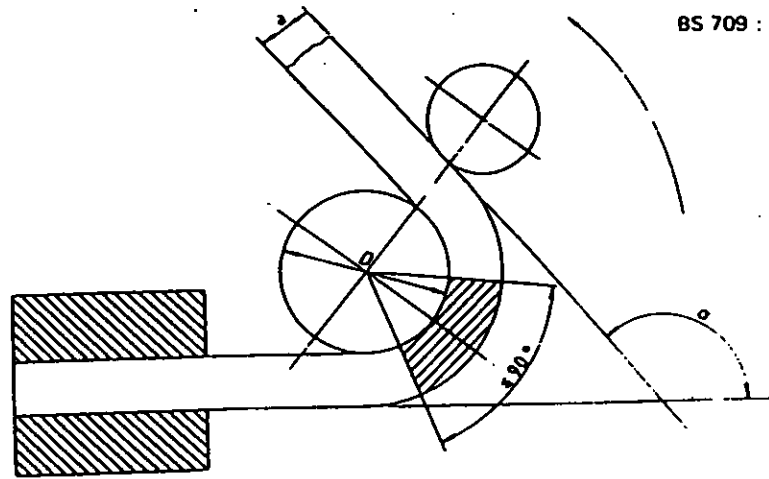


Figure 9. Method of testing transverse bend test specimen (diagrammatic only)

NOTES

- by using a roller to bend each test specimen around a mandrel. One end of the test specimen is firmly clamped, then a roller pushes the specimen around the mandrel in an arc to 180° or 90° as specified. The diameter of the former, or diameter of the mandrel, is typically four times the specimen thickness.



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(b)
Dimension is in millimetres
Figure 12. Bend test method using a roller

Evaluation of results

On completion of bending, any defects on the tension surface of the test specimen are investigated. Slight tearing at the edges of the test specimen may not be cause for rejection. What constitutes a test failure, and the action to take when a specimen fails, depends on specification requirements.

Nick-break test

The purpose of the nick-break test is to permit evaluation of any weld defects across the fractured surfaces of a butt weld.

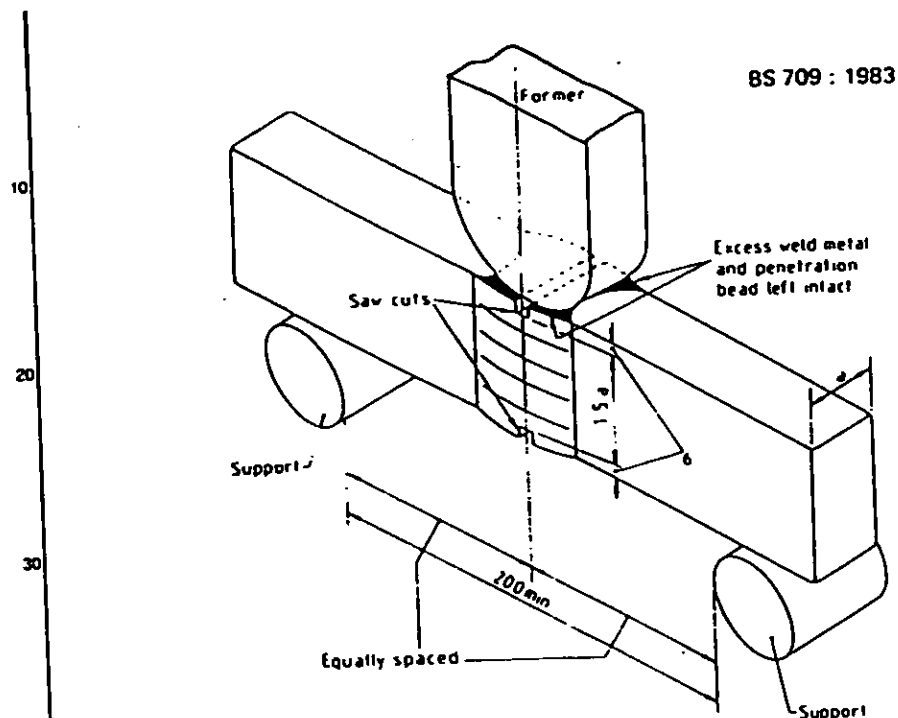
Two nicks (saw cuts approximately 2 mm deep) are applied to the specimen of similar shape to a bend test specimen, one on either side of the weld from the cap to the root. The weld reinforcement is left intact.

The test specimens are broken by bending or striking with a hammer. This causes the weld to fracture along the weakest zone close to the centre line of the weld. The fractured faces are then assessed visually. The test report would give a full description of the fractured faces including the presence of defects stating type and region.

BS N287&288 states:-

that during testing the test specimens shall not reveal any single flaw greater than 3 mm in any one direction. Flaws appearing or occurring at the corners of a specimen during testing shall be ignored during this evaluation. The diameter of the former shall be 4x the thickness of the specimen & bent to an angle of 120°.

NOTES



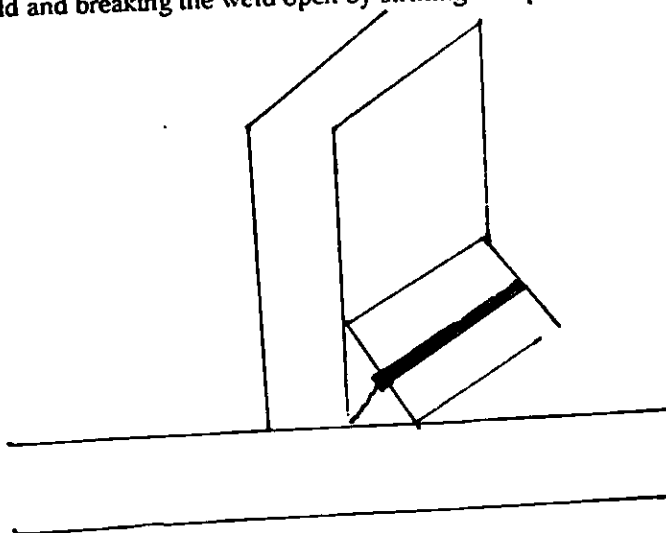
All dimensions are in millimetres

Figure 17. Method of fracturing nick-break test specimen (diagrammatic only)

Fillet weld fracture test

Fillet weld fracture test

This test has the same principle as the nick-break test, i.e. the test permits evaluation of any weld defects across the fractured surfaces of the tested weld. The test procedure involves making a single saw cut along the centre line of the weld face on a fillet weld and breaking the weld open by striking the specimen with a hammer.



NOTES

Toughness is the ability of a material to withstand cracking, which is essentially the opposite to brittleness.

Impact test (Dynamic test).

BS 131 - Notch bar tests

BS EN 10 045 - Charpy impact test on metallic materials

General

There are two main impact tests: the *Charpy V-notch test* and the *Izod test*. Both tests use a swinging pendulum which break accurately prepared notched test specimens; each specimen is broken with a single blow. Impact testing assesses *notch toughness* by measuring the energy absorbed by each test specimen during impact.

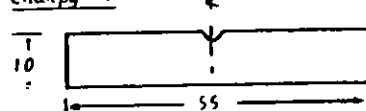
Naturally occurring notches, e.g. tool marks, undercut and lack of root penetration, reduce a components endurance, especially at low temperature. An impact test carried out on a weld determines the notch toughness of the weld at the test temperature.

Test procedure

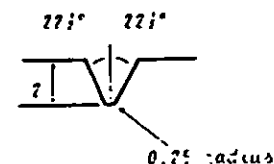
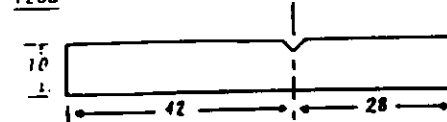
Test specimen dimensions and methods of support differ for the tests as shown below:

Dimensions in mm.

Charpy 'V'

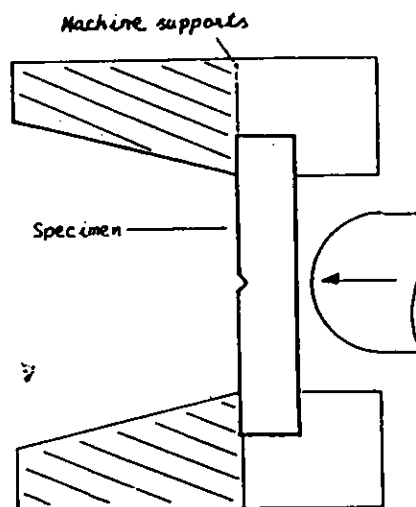


Izod

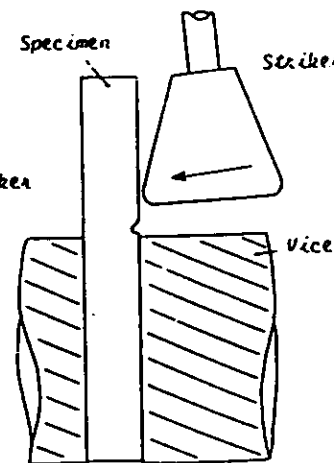


Notch detail for Charpy 'V' and Izod

Specimen thickness is dependant on specification and depends on wall thickness



Charpy



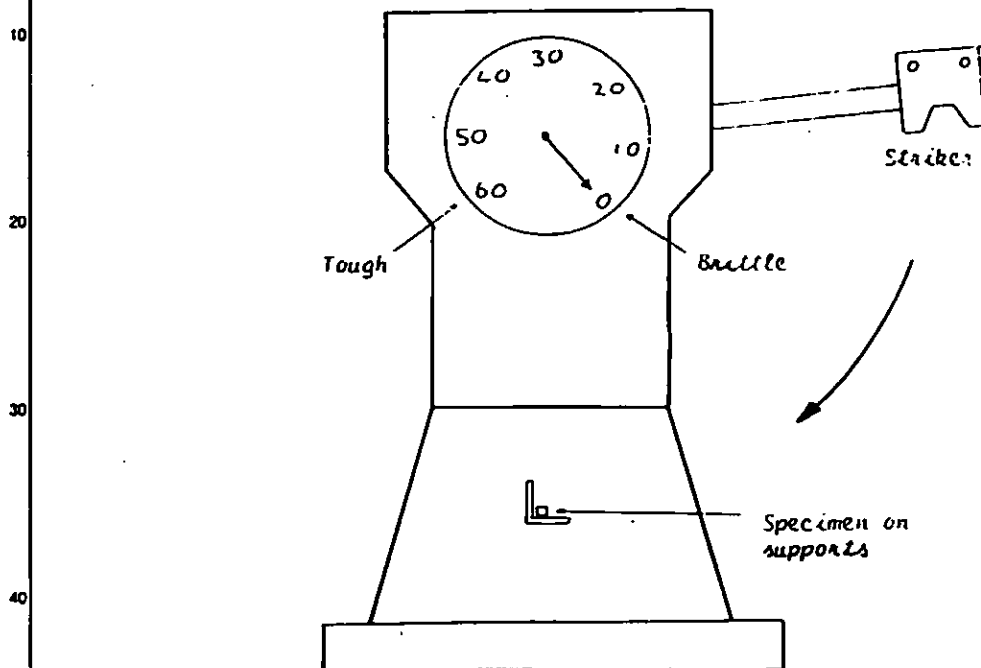
Izod

The specimen is positioned in the manner required for the test. The pendulum, is then raised to a pre-determined height and released; the pendulum hits the specimen which immediately fractures in the notch area - the pendulum then continues its swing. During fracture, energy from the pendulum will be absorbed by the specimen, more energy being absorbed by tough specimens compared to brittle specimens.

NOTES

The Joule (J) is the S.I. unit for energy.

The distance the pendulum swings after fracture—and consequently the absorbed energy—is measured by a pointer on a dial calibrated in Joules. The lower the value indicated, the more brittle the specimen, and conversely, the higher the reading the greater the toughness.



Arrangement of charpy machine (izod is similar principle)

Impact test specimens are normally taken in groups of three to allow for scatter results. The notch position relative to the weld, the test temperature(s), and the values required will depend on the application specification.

Minimum energies specified for steels are likely to be within the range of 10-50 J; actual values may be much higher.

Impact testing can also be used to make up ductile/brittle transition curves. This is done by testing a number of samples over a range of temperatures, then assessing the grain structures of the fracture faces on broken specimens and plotting the percentage area of brittle fracture against the temperature of the test.

Hardness test

General

Hardness testing may be used to determine the hardness gradient across a weld zone and parent material for comparison purposes. The maximum hardness of the weld zone may also be ascertained.

The hardness of a weld and h.a.z. will give an indication of the weldability of the material, and may be used to determine whether the welding procedures are correct or being correctly applied.

Two commonly encountered hardness tests carried out on welds are the *Brinell* and *Vickers hardness tests*.

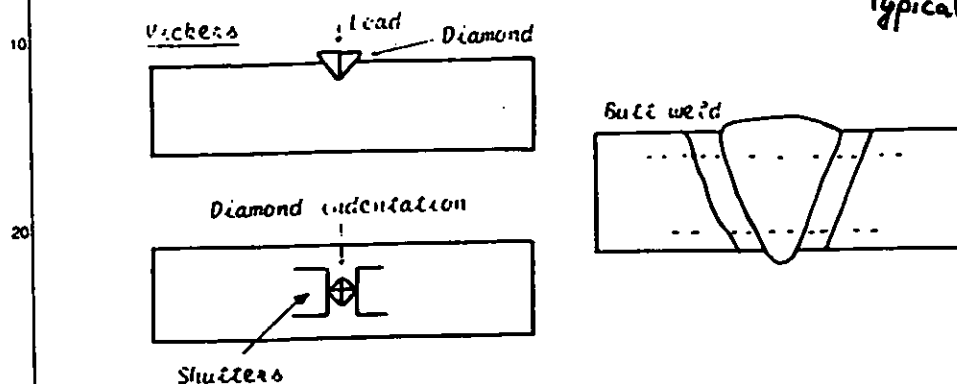
Vickers pyramid hardness test

BS 427 - Method for Vickers hardness test and for verification of Vickers hardness testing machines

NOTES

This test uses a small pyramid shaped diamond indenter with an angle of 136° between the opposite faces. A force is applied to press the indenter into the surface for a period of 10-15 s. The force applied is variable from 1 to 120 kgf (9.8-1176 N); the actual value to use would be obtained from the application specification.

Typical 10 kg



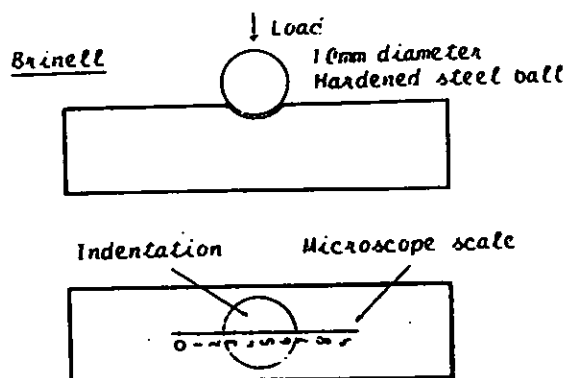
The diamond indenter leaves a pin tip sized square indentation on the surface of the test specimen which is measured by way of a built-in microscope. The diagonal dimension of the indentation is measured using two adjustable shutters; these are integrated with a digital readout, or similar, to give a value which corresponds to indentation depth and therefore hardness.

However, this displayed value is not the final hardness value. Firstly, both the diagonal lengths need to be measured and averaged. Secondly, the average value needs to be converted to a Vickers pyramid hardness value (H_V) by reference to special tables, or a formula, which also take into account the applied load. The final hardness value reported should include the load applied, e.g. 200 H_V at 10 kg.

Brinell hardness test

BS 240 - Method for Brinell hardness test and for verification of Brinell hardness testing machines

This test is carried out by hydraulically forcing a hardened steel ball, 10 mm in diameter, into the surface under test. The force used is 500, 1500, or 3000 kgf and is held for 15 s on steel.



A microscope with a calibrated lens is used to measure the width of indentation, this dimension can then be used with a reference chart or appropriate formula to obtain a Brinell hardness number.

NOTES

Macroscopic (macro) examination**General**

The term *macroscopic examination*, in this context, refers to the viewing of a polished weld cross-section using a low powered lens—typically $\times 5$ magnification—for the purpose of detecting and assessing weld defects, or for the purpose of measuring the actual size of defects already detected.

Macro-examination of welds is carried out on full thickness specimens which include reinforcement. The width of the cross-section should include the heat affected zone plus some parent material. The same test piece is sometimes used for hardness testing after macro-examination.

Test procedure

Test specimens are usually cut transversely from a weld. Each test specimen is then ground, polished and etched to the degree required by specification, e.g. for ferritic steels - P400 grade finish with an acid etch using 10-15% nital (nitric acid + alcohol).

After etching, the test specimen is examined visually. The intent is to disclose any cracks, lack of fusion, porosity, slag etc..

Microscopic (micro) examination

The term *microscopic examination*, in this context, refers to the viewing of a polished weld cross-section using a microscope at high magnification, e.g. $100\times$ or $1000\times$, usually for the purpose of grain structure analysis, although microscopic defects could also be detected and assessed. This test is primarily used by metallurgists.

The degree of preparation will be much higher than that required for macroscopic examinations, e.g. for ferritic steel: P1200 grade finish followed by $1\ \mu\text{m}$ polish using a diamond paste then an etch using 1-5% nital.

Crack tip opening displacement test (CTOD) Exam

BS 5762 - *Methods for crack opening displacement (COD) testing*.

CTOD is a test method for the determination of a metals resistance to the initiation of a crack resulting from notch defects.

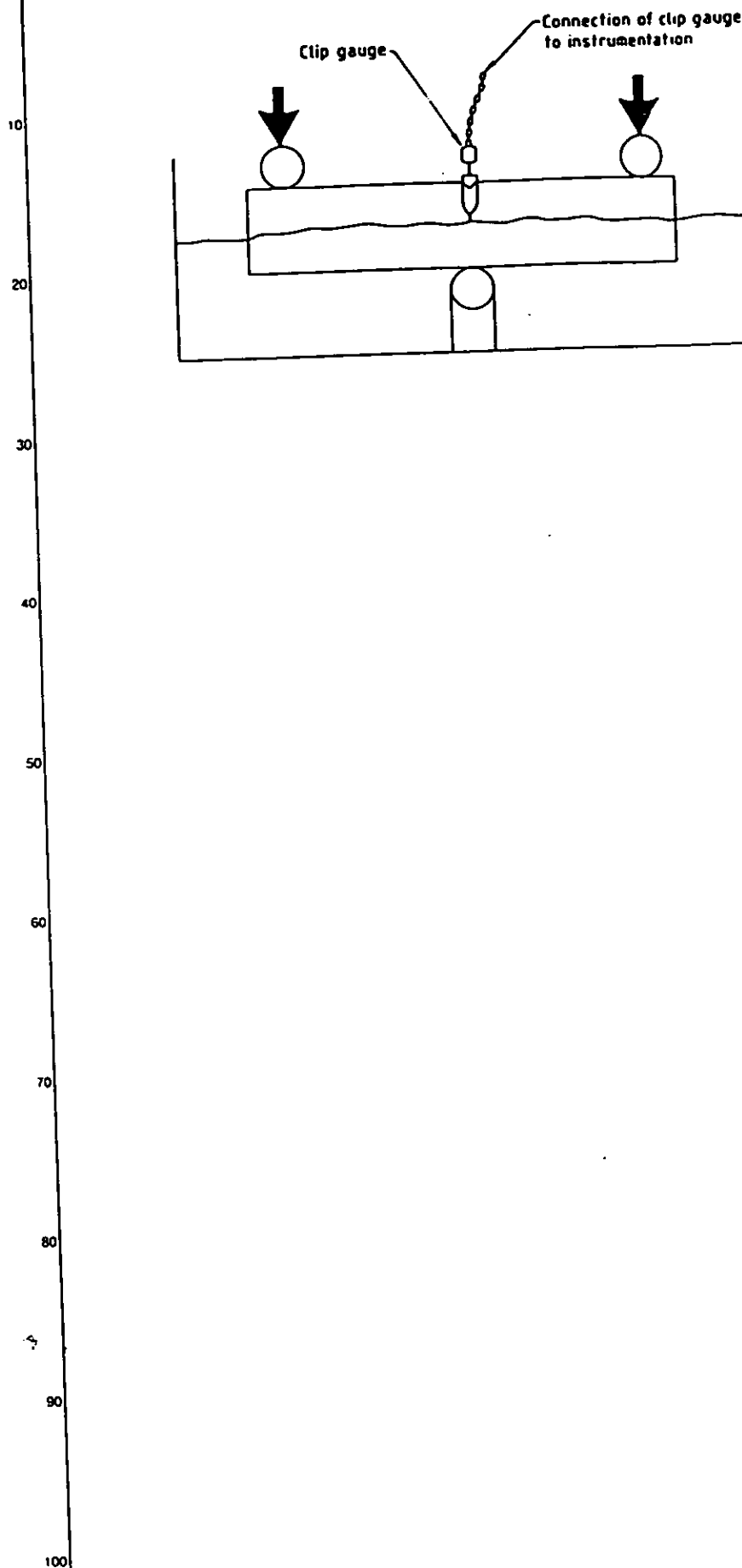
CTOD measures the elastic-plastic toughness of the metal in the ductile-brittle transition.

The propagation of a crack in a welded structure depends upon various factors including the material used, the size and sharpness of any notch present, operating temperature, the degree of restraint and welding procedure requirements.

The CTOD test permits full size specimens to be used irrespective of metal thickness, to which a notch of given width and depth is applied. The specimen is then subject to a high speed resonance load cycling to induce a crack at the root of the notch. The specimen is then cooled to test temperature and force is applied to open the notch using a three point bending rig. A clip gauge fixed to the mouth of the notch accurately measures the slow opening of the crack and a force sensing device enables the applied load to be plotted against displacement on a graph. The material beneath the crack will either deform plastically or fracture without loss in section.

fatigue crack

NOTES



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NOTES

Terminology

Weld defect (British):

"Any physical irregularity in the weld or heat affected zone, which may or may not affect the usefulness of a part."

Weld defect (American):

"A discontinuity the size, shape, orientation or location of which makes it detrimental to the useful service of the part in which it occurs, i.e. a discontinuity out of specification."

Discontinuity (American):

"Any interruption in the normal physical structure or configuration of a part, such as cracks, lack of fusion, inclusions or porosity. A discontinuity may or may not affect the usefulness of a part."

Weld defects

Cracks

Definition: A linear discontinuity produced by fracture. Cracks may be longitudinal, transverse, edge, crater, centreline, fusion zone, underbead, weld metal, or parent metal*.

There are many types of cracks, some of which only occur with certain types of material. Listed below are some crack types encountered.

1. Weld metal cracks:
 - a. solidification cracking (hot tearing),
 - b. hydrogen induced cold cracking (h.i.c.c.):
 - i. macro cracks,
 - ii. fissures,
 - iii. micro fissures,
 - iv. chevron cracks.
2. Heat affected zone cracks:
 - a. liquation cracks,
 - b. reheat cracks,
 - c. h.i.c.c..
3. Parent material/h.a.z.:
 - a. lamellar tearing.

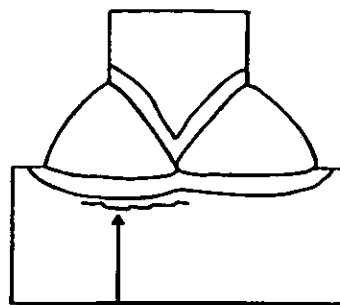
Because of the various crack types and causes, a welding inspector, under most circumstances, need only talk in terms of the position of a crack, e.g. longitudinal centre line crack; longitudinal crack in the h.a.z. of the root (*root underbead crack*); transverse crack; crater crack etc..

A crack is the most serious type of defect. If a crack exists in the weld zone, the application specification may require the entire weld to be removed (*cut out*) and rewelded, rather than carry out a localised weld repair. Some application specifications will permit a localised weld repair on the cracked area, but very few specifications will allow the acceptance of a detected crack, no matter how small.

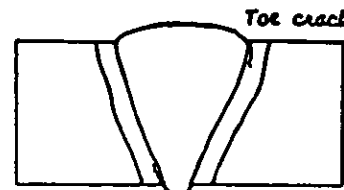
*Terminology to BS 499 :
Part 1 : 1991 : Welding terms
and symbols : Glossary for
welding, brazing and thermal
cutting, where indicated with
an asterisk (*).*

NOTES

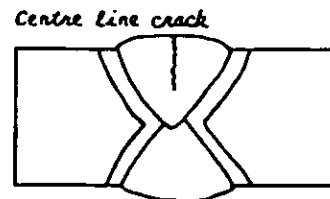
'T' butt joint



Lamellar tearing



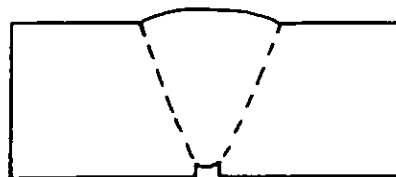
Root underbead crack



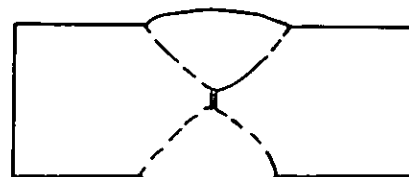
Incomplete root penetration

Definition: The failure of metal to extend into the root of a joint*.

Other terms for the same defect are: *lack of penetration* and *lack of root penetration*. In the case of double sided welds the terms: *lack of inter-penetration* and *lack of cross-penetration* may also be encountered.



Lack of root penetration



Lack of inter-penetration

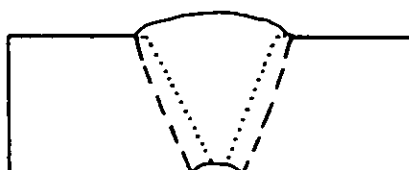
Causes:

- root faces too large,
- root gap too small,
- arc too long,
- wrong polarity,
- electrode too large for joint preparation,
- incorrect electrode angle,
- travel speed too high for current.

Root concavity

Definition: A shallow groove that may occur in the root of a butt weld*.

The terms *suckback* and *underwashing* may also be encountered.



Causes:

- root face too large,
- insufficient arc energy,
- excessive back purge pressure with t.i.g. welding.

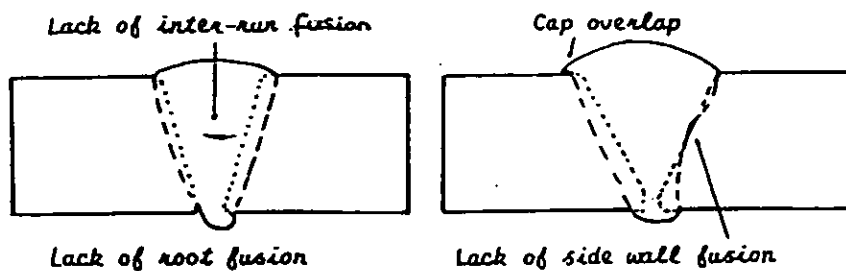
NOTES

Lack of fusion

Definition: Lack of union in a weld*:

- between weld metal and parent metal,
- between parent metal and parent metal,
- between weld metal and weld metal.

Lack of fusion can be sub-divided as shown in the diagram:



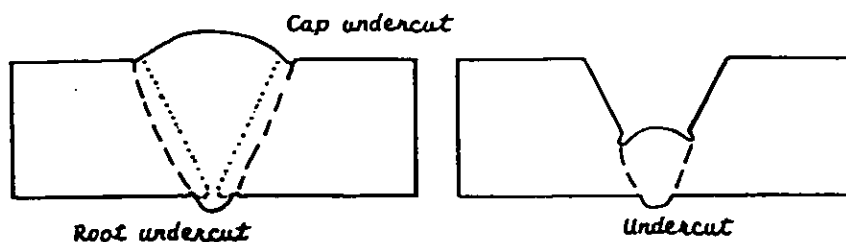
Causes:

- a. contaminated weld preparation - prevents the melting of material beneath,
- b. amperage too low,
- c. amperage too high - may cause welder to increase his travel speed resulting in a lack of melting on the underlying metal,
- d. excessive inductance in m.i.g. or m.a.g. dip transfer welding.

See also causes for incomplete root penetration.

Undercut

Definition: An irregular groove at the toe of a run in the parent material, or in previously deposited weld metal, due to welding*.

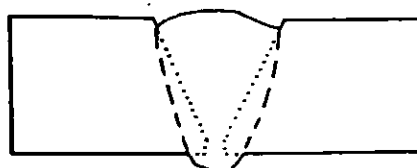


Causes:

- a. excessive welding current,
- b. welding speed too high,
- c. incorrect electrode angle,
- d. excessive weaving,
- e. electrode too large.

Incompletely filled groove

Definition: A continuous or intermittent channel in the surface of a weld, running along its length, due to insufficient weld metal. The channel may be along the centre or along one or both edges of the weld*.



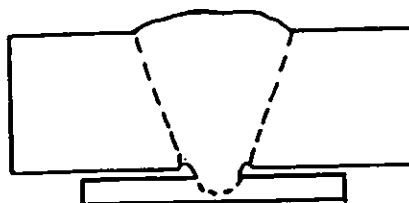
NOTES

Causes:

- insufficient weld metal deposited,
- improper welding technique.

Shrinkage groove

Definition: A shallow groove caused by contraction in the metal along each side of a penetration bead*.



Gas pores/porosity

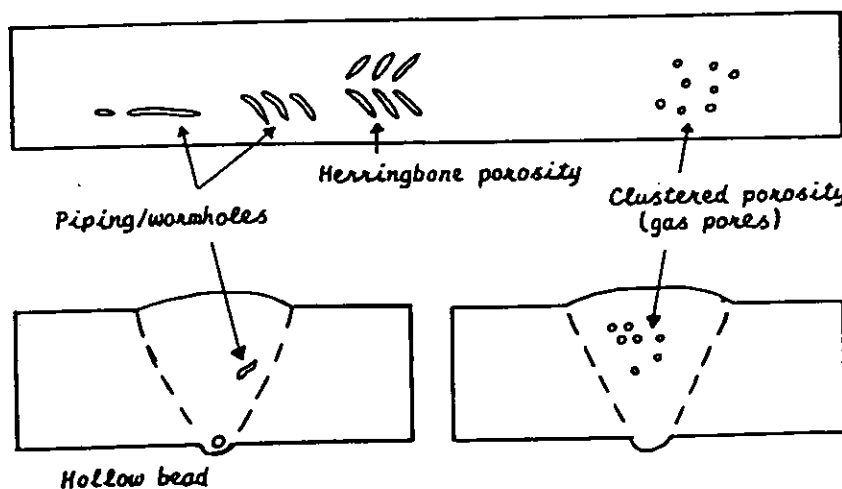
Definition: A *gas pore* is a cavity, generally under 1.5 mm in diameter, formed by entrapped gas during the solidification of molten metal*.

Definition: *Porosity* is a group of gas pores*.

Other terms which relate to entrapped gas in welds are:

- Blowhole - a cavity generally over 1.5 mm*.
- Wormhole (piping) - an elongated or tubular cavity*.
- Hollow bead - elongated porosity in the root bead (pipeline terminology).
- Herringbone porosity - wormholes side by side taking on a herringbone pattern.

Hollow bead is terminology used on pipelines where it is commonly encountered on m.m.a. vertical down (stovepipe) root beads using cellulose electrodes.



Causes (all types):

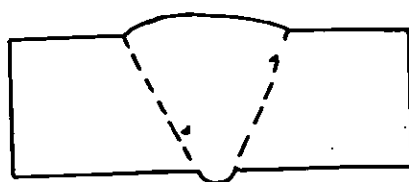
- excessive moisture in the flux,
- excessive moisture on the preparation,
- contaminated weld preparation: scale, oxides etc.,
- use of low welding current,
- arc length too long (especially with basic hydrogen controlled electrodes),
- damaged electrode flux,
- incorrect weaving technique,
- removal of gas shield, e.g. wind on site.

Slag inclusion

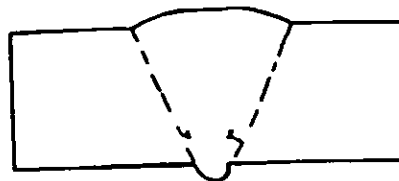
Slag is defined as: a fused, non-metallic residue produced from some welding processes*.

NOTES

A **slag inclusion** is an entrapped non-metallic deposit in the weld originating from the welding flux. Linear slag inclusions, or **slag lines**, almost exclusively exist at the toes of a weld pass. Equiaxed slag inclusions may exist anywhere in the weld.



Slag/slag lines



Parallel slag lines/wagon tracks

Causes:

- insufficient cleaning between passes,
- contaminated weld preparation,
- welding over an irregular profile,
- incorrect welding speed,
- arc too long.

Tungsten inclusion

Definition: An inclusion of tungsten from the electrode in tungsten inert-gas welding*.

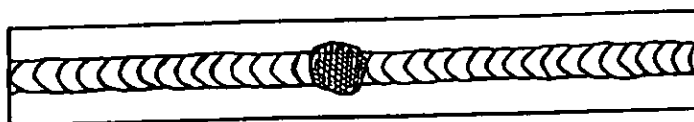
Copper inclusion

Definition: An inclusion of copper due to the accidental melting of the contact tube or nozzle in self-adjusting and controlled-arc welding, or to pick-up by contact between the copper nozzle and the molten pool in tungsten inert-gas welding*.

Burn through

Definition: A localised collapse of the molten pool due to excessive penetration, resulting in a hole in the weld run*.

Burn throughs are usually associated with the roots of butt welds.



Burn through (hole in root)

Causes:

- excessive amperage during the welding of the root or hot pass on butt welds,
- excessive root grinding, which may cause the second pass to burn through,
- improper welding technique.

Crater pipe

Definition: A depression due to shrinkage at the end of a weld run, where the source of heat was removed*.

Crater pipes must not be confused with burn throughs or gas pores.



Crater pipe

Cause:

- Deoxidation reactions and liquid to solid volume change.

NOTES

Arc strike (stray flash)

Definition: Damage on the parent material resulting from the accidental striking of an arc from the weld*.

Arc strikes may have a very brittle structure, especially on steels with a high carbon equivalent.

Causes:

- a. electrode straying onto parent material,
- b. electrode holder with poor insulation touching workpiece,
- c. poor contact of the earth clamp.

Spatter

Definition: Small droplets of electrode material which have strayed away from the arc, which may or may not have fused to the parent plate.

Causes:

- a. excessive arc energy,
- b. excessive arc length,
- c. damp electrodes,
- d. arc-blow.

Classification and significance of defects

Defects may be classified depending on their shape:

- **Planar defects:** linear from at least one dimension; crack like, e.g. cracks, lack of fusion. Relative to other defects, these defects usually have a high significance.
- **Linear volumetric defects:** e.g. slag lines, elongated porosity.
- **Equiaxed defects:** rounded and non-linear, e.g. gas pores, slag inclusions. Relative to other defects, these defects usually have a low significance.

The position of a defect in the cross-section of a weld is also an important consideration. Stress is more concentrated at a surface and corrosion may also be taking place in the region, therefore a non-planar defect breaking the surface may be classed as highly significant defect.

The actual defect acceptance or rejection will depend on the *defect acceptance levels* listed in the relevant specification.

Defect acceptance levels

General

Defect acceptance levels are included in certain specifications - especially in application specifications. The tolerances are usually determined by the use of fracture mechanics, a subject which uses mathematical calculations and mechanical tests, in order to arrive at maximum defect dimensions permissible prior to remedial action.

Some specifications contain defect acceptance tolerances which are more strict than others, depending on the *criticality rating* of the structure or application to which the specification applies.

Overall criticality rating depends on a variety of factors including: the stresses involved, e.g. pipe pressures; the environment, e.g. contact with corrosive chemicals; erosion, e.g. from fluid flow.

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The following list shows a variety of applications in a descending order of criticality:

1. Vessels and pipework for radioactive substances.
2. Pressure vessels welded to BS 5500 or the ASME boiler code.
3. Pipework welded to BS 2633.
4. Pipelines welded to BS 4515, API 1104, BGC PS P2.
5. Bridges, ships and general construction.

Repair welding

If not properly controlled, it is possible for a weld repair to be more detrimental than the original defect, due to adverse microstructural effects in the h.a.z., especially on high Ceq% materials, therefore separate repair welding procedures are normally required.

Some specifications may not permit the same weld area to be repaired more than once, again due to adverse metallurgical effects.

Some specifications may limit the length of repairs, taking into consideration resulting metallurgical changes and stresses acting on the rest of the *unopened* weld.

Removal of defective areas

The specification or procedure will govern how the defective areas are to be removed. At least one of the following removal methods will be used:

- grinding,
- gouging using an arc process,
- gouging using a fuel gas process,
- chipping,
- machining,
- filing.

Prior to repair welding, the defective area would normally be removed or blended without impinging onto the parent material, i.e. the original weld joint profile would normally have to be maintained. If unacceptable defects exist in the parent material, e.g. surface laminations, arc strikes, gouges etc., the action to be taken will again depend on the specification requirements. Some specifications will allow grinding and re-welding, whilst others will require the defective area to be cut off if the material thickness is reduced below certain limits after grinding/blending.

NOTES

Cracks found within weld zones may be divided into two broad categories:

1. **Weld process cracks:** attributable to the weld process itself.
2. **Service induced cracks:** attributable to some external influence during service such as vibration or cyclic thermal stresses.

Weld process cracks are categorized/termed in many ways, but there are essentially only four crack types caused through welding:

1. **Solidification cracks**
2. Hydrogen induced cracks (HIC).
3. Lamellar tearing.
4. Reheat cracks.

There are also many ways to categorize/term service induced cracks. The following list identifies the main types:

1. Brittle fracture.
2. Ductile fracture.
3. Fatigue fracture.
4. Creep failure.
5. Stress corrosion cracking.
6. Hydrogen cracking induced by corrosion.

Cracks may also be termed in relation to their direction or shape:

- Longitudinal with the weld axis.
- Transverse with the weld axis.
- Branched.
- Multi-directional.
- Chevron.

Terminology used may also indicate the location of the crack(s) relative to the weld:

- Edge.
- H.a.z..
- Centreline.
- Crater.
- Fusion zone.
- Underbead.
- Parent metal.

Cracks may be smooth or jagged in profile. Some cracks have branches, some are more multi-directional and some occur intermittently.

Weld process cracks

Solidification cracking

Cracking that takes place during the weld solidification process is termed either *hot cracking* or *solidification cracking* and occurs in all steels which have a high sulphur content—sulphur causes low ductility at elevated temperatures.

In order for a crack to develop the solidifying metal must be subjected to a high tensile stress, this may be present as a result of weld metal contraction combined with high restraint. Solidification cracks usually occur longitudinally down the centre of a weld

The low melting point of phosphorous compounds may also be a problem and may lead to solidification cracking.

NOTES

because of the segregation of impurities and have a blunt profile compared to other crack types. A *Crater* is a type of *Surface* crack and is often *Y* shaped, hence the alternative name *Crater*. If a high longitudinal stress is applied, it may cause transverse cracks to develop, e.g. on large *slabs*.

Liquation cracking

Solidification cracks in welds may be due in part to the presence of materials within the metal which have a lower melting point than that of the metal itself. These low melting point materials usually accumulate at the grain boundaries and can cause problems. In the parent metal, this occurs where the temperature is high enough to cause melting of the grain boundary. If this melting occurs in the presence of a high tensile (contraction) stress, then the boundaries will be pulled apart and a *liquation crack* occurs.

Within the steel itself, sulphur is the major liquation material. If the welding involves a very high heat input, the sulphur in the HAZ is taken into solution by the surrounding steel and precipitates out during cooling as sulphides, causing embrittled grain boundaries which significantly weaken the steel. If such an occurrence has happened, the steel is said to be *liquated*. This also causes this particular form of liquation.

Liquation cracks are very small and can initiate hydrogen cracking.

Hydrogen induced cracking

See other course notes.



Lamellar tearing

Lamellar tearing is a form of *intergranular* cracking which may occur in the parent plate or HAZ of a weld. It is caused by the presence of *slag* inclusions where the fusion boundary of the weld is formed. This plate is *rolled* and the tearing only occurs in the *rolled* direction. It is associated with restrained joints that are subjected to *transverse* stresses. It is seen in fillet welds joining *thick* plates, where the *transverse* stresses are high, although other non-metallic inclusions may be present. The presence of hydrogen increases a steel's susceptibility to lamellar tearing.

The through thickness ductility of the parent material may be assessed by using the *short tensile test* - see BS 544.

Re-heat cracking

Re-heat cracking - also known as *stress relaxation* - mainly occurs in the HAZ of welds, particularly in low alloy steels during post weld heat treatment or service at elevated temperatures.

Most alloy steels are subject to an increase of embrittlement of the coarse grained region of the HAZ when heated above 600°C, the problem is worse with thicker steels containing Cr, Cu, Mo, V, Nb and Ti; S and P also have an influence. Typical steels susceptible would be the *Cr-Mo* types, e.g. *creep resisting steels*.

During post weld stress relief and at high operating temperatures, the residual stresses will be relieved by creep deformation which involves grain boundary sliding and grain deformation. If, due to high creep strength these actions cannot occur, the grain boundaries may open up into cracks.

Re-heat cracks most frequently occur in areas of high stress concentration and existing defects. They are not unknown in the weld area where the cracks may originate from sharp profiles, e.g. incomplete root penetration or at the toes of badly shaped fillet welds.

In the HAZ area, the defect which promotes re-heat cracking could be an existing liquation crack

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Precautions against re-heat cracking include toe-grinding, elimination of partial penetration welds, the rejection of poor weld profiles, the selection of steels resistant to liquation cracks, the use of the lowest strength weld metal acceptable and controlled post weld heat treatment.

Note: A crack which has only been found after post-weld heat treatment is not necessarily a reheat crack.

Service induced failures

Brittle and ductile failure

See Unit W15S.

Fatigue cracks

Fatigue cracking is a service failure which occurs under cyclic stress conditions. It normally occurs at a change in section, e.g. groove, radius, step, weld toe etc., therefore design and workmanship are important to minimise failure by fatigue.

All materials are susceptible to fatigue failure. Since design and workmanship play a major part, ferrous based materials have an endurance limit applied to one grade of steel in a specific heat treated condition operating within specific parameters, below this limit fatigue is unlikely to occur. Other metals will all have the potential to fail by fatigue given the required conditions.

Fatigue failures start at a specific point and propagate with each stress cycle at a rate that depends on the applied stress. Fatigue failure is easily identified by beach markings on the fractured face. Final failure can be any other mode of fracture, e.g. brittle or ductile failure.

Thermal fatigue cracks may occur if the cyclic stresses are provided by frequent temperature changes producing fluctuating thermal stresses.

Corrosion fatigue failure results from a combination of cyclic stress and a corrosive environment at the fatigue site.

Creep/creep failures *Constantly applied load at elevated temperature*

Deformation by creep is the slow plastic deformation of a metal, under a constant stress at any temperature. The plastic deformation is very small compared with normal tensile loading whilst the temperature range for creep in a given material is between 0.5 to 0.7 of its melting point expressed in degrees Kelvin (°K). Creep may lead to fracture.

The stages of creep are:

1. Primary creep
2. Secondary creep - steady state constant rate creep - the most important stage
3. Tertiary creep - The stage when the rate of extension accelerates and leads to failure.

Creep may occur in any situation where a steady state of stress exists, e.g. ranging from lead pipes at room temperature to steam and power generating plant at 450°C to 500°C.

Materials such as Cr-Mo-V have been developed for high temperature service which resist creep by blocking the plastic deformation slip systems.

Stress corrosion cracking

This type of cracking may occur in materials in a state of tensile stress and in contact with a corrosive medium. The level of stress which can cause the cracking may be well below the yield point of the material.

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Stress corrosion cracks are surface breaking and are found at any sharp change in section, notch or crevice. especially in structures which have not been stress relieved. Both ferrous and non-ferrous materials are susceptible to stress corrosion cracking.

Weld decay in austenitic stainless steels

Weld decay, also known as sensitization, occurs in austenitic stainless steels, e.g. 18-8 type, when they are heated in the temperature range 450°C to 850°C. At this temperature range carbon is absorbed by the chromium and chromium carbide is precipitated at the grain boundaries as the metal cools down. This causes a local reduction in chromium content which has the affect of lowering the resistance to corrosive attack allowing *rusting* to occur.

Weld decay is prevented in austenitic stainless steels by the addition of niobium or titanium, but the most common method to prevent weld decay is to decarburize the molten steel.

18% chrome.
8% nickel.

10
20
30
40
50
60
70
80
90
100

NOTES

Consumables used in arc welding may be a combination of wire and flux, or bare wire. Flux may be present either as a core - for some m.a.g. applications; as a granular additive - for s.a.w.; or as a coating - for m.m.a. welding. Exceptions to this rule include the m.i.g. and t.i.g. processes which use bare wire consumables and no flux.

Consumables which are added separately to the weld pool may be known as *filler rods* or *filler wires*; if they are part of the welding circuit providing one end of the arc, they are known as *electrodes*.

Filler rods and wires

BS 4165 - *Electrode wires and fluxes for the s.a.w. of carbon steel and medium tensile steel.*

BS 2901 - *Filler rods and wires for gas shielded arc welding; (5 parts).*

BS 2901 specifies the requirements, including chemical compositions, for filler rods and wires for the t.i.g. and m.i.g./m.a.g. processes. The following shows two commonly used wire types for steel:

Type A17 - double deoxidized: C 0.12% max.; Si 0.2-0.5%; Mn 0.85-1.4%;
P 0.04% max.; S 0.04% max.; Cu 0.5% max.

Type A15 - triple deoxidized: C 0.12% max.; Si 0.3-0.9%; Mn 0.9-1.6%;
P 0.04% max.; S 0.04% max.; Cu 0.5% max.;
Al 0.04-0.4% max.

The requirements in all cases are that the rods and wires have a smooth finish, free from surface imperfections, corrosion products, grease or other foreign matter which would adversely affect the quality of the weld or the operation of the welding equipment. In addition, wires should be free from kinks, waves, sharp bends or twists.

Filler wires used for welding steel with the m.a.g. process are coated with a very thin layer of copper to protect the wire from corrosion. This copper layer also improves the electrical pick up via the contact tube.

The chemical composition is stated in individual specification parts relating to particular materials; for example:

- Part 1 : *Ferritic steels*: these consumables may be supplied either bare or with a protective copper coating, and would be double or triple de-oxidized.
- Part 2 : *Austenitic stainless steels*.

M.m.a. consumables (electrodes)

Development history

1900: M.m.a. welding was introduced using bare wire as a consumable electrode. The arc was difficult to initiate and maintain, and the electrode burned off erratically, frequently freezing in the weld pool. The weld itself, which was open to atmospheric attack, was porous, lacked penetration and fusion, and was highly contaminated with oxides and nitrides.

Development was restricted until it was noticed that rusty and/or mud coated wire gave increased arc stability and improved weld quality.

1907: The first covered electrodes dipped in lime were developed. Asbestos was introduced to control the melting of the *flux*, which burned slightly later than the core wire; this improved the transfer characteristics of the molten metal, penetration and weld shape, but they were only suitable for use with d.c. because of instability.

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1915: *Cellulose* electrodes developed by the addition of wood pulp, cotton waste and other organic materials to the flux coating. Cellulose introduced into the arc will produce large volumes of gas, including hydrogen, and creates an effective shield against the atmosphere. Modern electrodes of this type rely more on the gas shield than on the slag to protect the weld, and are usually thinly coated with flux. At the time of development they could only be used with d.c..

1935: *Rutile* electrodes containing approximately 50% rutile titanium dioxide (TiO_2) were developed. Rutile is mainly a slag former but it also stabilizes the arc and lowers the operating voltages required. Rutile covering enabled m.m.a. to be used with a.c., which effectively reduced the overall cost of the process and made it more acceptable to industry.

1947: *Basic coated low hydrogen* electrodes were developed. The Second World War had forced the construction industry to use the m.m.a. welding process, mainly for the increased speed of fabrication obtained, however as steel quality improved, the electrodes tended to lag behind, and probably still do today. This created a lot of metallurgy related problems, mainly due to the high hydrogen content of the cellulose electrodes, or the low strength of the rutile electrodes. The basic coated, low hydrogen electrodes were able to overcome most of the initial difficulties in both these areas.

1955: *Iron powder* electrodes were introduced. Iron powder can be added to all electrode coverings and has the advantages of almost doubling the deposition rate and increasing the time spent welding, giving longer beads and less stop/starts. It also reduces the operating voltage making a.c. an even more feasible proposition and enables *touch* welding techniques to be used. Iron powder electrodes improve weld pool fluidity which is fine for production welds in the flat position but requires greater operator skill during positional welding.

Future trends: The main areas of future consumable advancement, will probably be higher strength uses on carbon steels with increased deposition rates and arc stability, with an overall reduction in the operator skill level required for their use. All these and other factors will be a result of flux additives, because very little can be done with the core wire which is usually standard for C and C-Mn steels and has a typical composition of 0.2% C, 0.5% Mn, 0.02% Si with Fe making up the balance.

Functions of flux

The functions of a flux can be summarised as follows:

- to provide a gas shield protecting the arc and weld pool from atmospheric oxygen and nitrogen which can cause inclusions and reduce the weld ductility.
- to provide a slag which gives additional shielding to the weld pool and assists in its manipulation during welding. The slag also creates a thermal blanket slowing down cooling and refining the metallurgical structure of the weld metal,
- to improve the physical properties of the arc. The coating additives improve arc initiation, stability and ease of use,
- to introduce weld metal alloys, iron powder, deoxidants etc. thereby improving metallurgical properties; lowering oxygen and nitrogen levels, and hydrogen levels in certain cases; and increasing deposition factors and overall efficiency.

Types of flux covering

Introduction

Rutile, *cellulosic*, and *basic* fluxes are the common types of coverings for m.m.a. electrodes; others include *acid* and *oxidizing* coverings. Some electrodes may be produced solely for a particular contracts requirements.

Rutile

Rutile coated electrodes are used mainly on general purpose work such as mild steel fabrications, low pressure pipework, support structures, brackets etc.. A medium

NOTES

weight coating of titanium dioxide plus fluorspar, gives a fluid fast freezing slag, which makes the electrode suitable and easy to use in all positions, but not often vertical down. Electrodes of this type are very popular throughout the welding industry.

Rutile fluxes should be kept dry but never baked.

The flux constituents include the following:

- a. Titanium dioxide (rutile) - slag former and secondary ionizer.
- b. Clay - binding agent.
- c. Sodium silicate - main ionizer.

Cellulosic

This coating designation indicates a high cellulose content which produces large volumes of gas in the region of the arc. The principle protection mode of cellulosic electrodes is via this gas shield which consists of H_2 , CO, CO_2 and H_2O . The most important of these gases is the hydrogen (H_2) which has the effect of increasing the arc voltage with a corresponding increase in power; this develops a very forceful deeply penetrating arc.

Cellulosic coated electrodes also have a rapid burn off rate, a fast freezing weld pool and thin slag, this makes the electrodes especially suitable for vertical down and overhead work. One of the main uses of cellulosic electrodes is the stovepipe welding of high strength large diameter pipelines and storage tanks; good quality penetration beads can be produced.

The completed welds have a rough appearance with coarse uneven ripples; the spatter content is higher than that achieved with other electrode types.

Cellulose fluxes are hygroscopic and are designed to hold between 4-7% moisture; they must be kept dry but never baked.

The flux constituents include the following:

- a. Cellulose (mainly wood pulp) - gas former. High in H_2 which increases arc voltage and therefore overall power of the arc - this may be detrimental for some steels.
- b. Titanium dioxide - slag former. A minor addition only - not enough to affect ionization.
- c. Sodium silicate - main ionizer. Usually permits welding with d.c.+ve. Potassium silicate is an alternative - this ingredient often permits welding with all current forms but is expensive.

Basic

Basic coated electrodes have a high limestone and fluorspar content, and were developed to produce weld metals with a low hydrogen content. Limestone has excellent arc stabilizing (ionising) qualities and produces a carbon dioxide gas shield.

Prior to use they may be baked at temperatures up to approximately $500^\circ C$, depending on the particular make of electrode, to drive off moisture without damage occurring to the coating.

Basic coated electrodes are used extensively because of their ability to weld low alloy, high and medium tensile steels, and steels with a high sulphur content without any real danger of solidification cracking.

Basic coated electrodes also reduce the possibility of hydrogen induced cracks in the weld and/or h.a.z. area, but this factor is dependant upon them being properly dried before use. Typical precautions include heated storage areas, sealed containers, pre-issue ovens, and quivers for on-site welding.

BS 639 states that for an m.m.a. electrode to be classified as *hydrogen controlled*, it must produce less than 15 ml of hydrogen per 100 g of weld metal deposited. With proper control this can be brought down to less than 5 ml H_2 /100 g of weld metal.

To prevent atmospheric contamination of the weld, a short arc with minimum weave must be maintained which makes manipulation difficult; therefore basic coated

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electrodes generally require a higher degree of operator skill. Another disadvantage of basic coated electrodes is that when positional welding is carried out, the conventional or vertical up technique must be used. This can be counter productive and expensive; however, there are basic coated electrodes available which can be used in the vertical down direction so that a combination of high integrity weld metal and high speed positional welding are combined.

The flux constituents include the following:

- a. Limestone (calcium carbonate) - gas former (mainly CO_2) and secondary ionizer.
- b. Fluorspar - slag former. Similar to titanium dioxide but higher quality.
- c. Sodium silicate or potassium silicate - main ionizer.

BS 639 electrode coding

The BS 639 - *Covered carbon and carbon manganese steel electrodes for manual metal-arc welding*, classifies electrodes and designates a flux covering code.

EXAMPLE CODING: E5143B 160 24H

1. The letter E. A flux coated electrode for use with the manual metal arc welding process. There are no alternatives to the letter E.
2. The number 51. Relates to the tensile strength and the minimum elongation values of the deposited weld metal. The only possible numbers are 43 and 51; these relate to the following values:
 - a. 43 - the weld metal has a tensile strength within the range of 430-550 N/mm² and a yield stress of not less than 330 N/mm².
 - b. 51 - the weld metal has a tensile strength within the range of 510-650 N/mm² and a yield strength of not less than 360 N/mm².

The minimum elongation value related to the above is also dependent on the next digit - the value will be between 18% and 24%.
3. The numbers 4 and 3. A second group of two independent numbers give information on notch toughness related to Charpy V-notch impact tests.
4. The letter B. This indicates flux type; the following letters are options:
 - a. B = basic
 - b. BB = basic, high efficiency
 - c. C = cellulosic
 - d. R = rutile
 - e. RR = rutile, heavy coated
 - f. S = other types

Note: The above part of the code is sometimes referred to as the STC code (STC = strength, toughness and covering). If a consumable is to have a BS 639 coding, the above information has to be supplied as a minimum; the following part of the code is optional.

The number 160. This indicates the electrode efficiency to the nearest 10% above 110%, which relates basically to the amount of iron powder present; e.g. if the core wire provides 100% of the weld metal and an extra 60% is deposited, then the electrode has an efficiency of 160%.

5. The number 2. This indicates specific welding positions in which the electrode can be used.
6. The number 4. This indicates the welding current and voltage conditions.

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7. The letter H. The code may include this letter when no more than 15 ml of hydrogen is present per 100 g of weld metal deposited, i.e. when the letter *H* is present the electrode may be classed as *hydrogen controlled*.

BS 639 : 1986

Covered electrodes for the manual metal arc welding of carbon and carbon manganese steels

The code up to the electrode covering is compulsory, the rest may be added at the manufacturer's discretion.

PROCESS
Covered MMA electrode

COVERING
B basic
BB basic (high efficiency)
C cellulosic
R rutile
RR rutile (heavy coated)
S other types

EFFICIENCY
% recovery to nearest 10% (above 110)
(H)
Indicates hydrogen controlled (below 15ml/100g)

E	43	32	R	140	3	1	
E	51	33	B	160	2	0	H

POSITION DIGIT
1 all positions
2 all positions except vertical down
3 flat and, for fillet welds, horizontal/vertical
4 flat
5 flat, vertical/down and, for fillet welds, horizontal/vertical
9 any position or combination of positions not classified above

SECOND GROUP			
First Digit	Temperature for impact value of 28J, °C	Second Digit	Temperature for impact value of 47J, °C
0	Not specified	0	Not specified
1	+20	1	+20
2	0	2	0
3	-20	3	-20
4	-30	4	-30
5	-40	5	-40
		6	-50
		7	-60
		8	-70

ELECTRICAL DIGIT		
Digit	Direct Current Recommended electrode polarity	Alternating current Minimum open-circuit voltage
0	Polarity as recommended by manufacturer	V Not suitable for use on a.c.
1	+ or -	50
2	-	50
3	+	50
4	+ or -	70
5	-	70
6	+	70
7	+ or -	80
8	-	80
9	+	80

FIRST GROUP					
Electrode designation	Tensile strength	Minimum yield stress	Minimum elongation		
			When digit of group 2 is 0 or 1	When digit of group 2 is 2	When digit of group 2 is 3, 4 or 5
E43	N/mm ² 430-550	N/mm ² 330	% 20	% 22	% 24
E51	N/mm ² 510-650	N/mm ² 360	% 18	% 18	% 20

NOTES

AWS electrode coding

A frequently encountered electrode classification code for m.m.a. welding is the AWS A5.1 - *Specification for carbon steel electrodes for shielded metal arc welding*.

The code consists of a letter followed by four digits and in one case a final letter.

Example coding E7018M

1. E Electrode.
2. 70 70,000 psi specified minimum ultimate tensile strength.
3. 1 Welding position suitable.
4. 8 Flux type and electrical characteristics.
5. M Meets military requirements.

M.m.a. electrodes for steel which are encountered with a coding similar to any of those shown in the table below, e.g. E7010G, E8016-B1, they will be coded in accordance with the specification AWS A5.5 - *Specification for low alloy steel covered arc welding electrodes*.

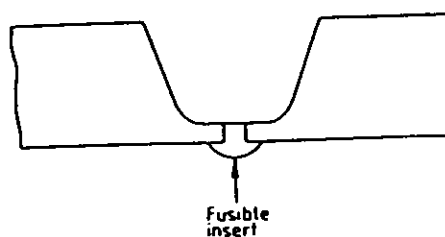
The complete AWS A5.1 (1991) electrode classification is as follows:

AWS Code	Type of Covering	Welding Position	Type of Current
E6010	High cellulose sodium	F, V, OH, H	dcep
E6011	High cellulose potassium	F, V, OH, H	ac or dcep
E6012	High titania sodium	F, V, OH, H	ac or dcen
E6013	High titania potassium	F, V, OH, H	ac, dcep or dcen
E6019	Iron oxide titania potassium	F, V, OH, H	ac, dcep or dcen
E6020	High iron oxide	H-fillets F	ac or dcen ac, dcep or dcen
E6022	High iron oxide	F, H	ac or dcen
E6027	High iron oxide, iron powder	H-fillets F	ac or dcen ac, dcep or dcen
E7014	Iron powder, titania	F, V, OH, H	ac, dcep or dcen
E7015	Low hydrogen sodium	F, V, OH, H	dcep
E7016	Low hydrogen potassium	F, V, OH, H	ac or dcep
E7018	Low hydrogen potassium, iron powder	F, V, OH, H	ac or dcep
E7018M	Low hydrogen iron powder	F, V, OH, H	dcep
E7024	Iron powder, titania	H-fillets, F	ac, dcep or dcen
E7027	High iron oxide, iron powder	H-fillets F	ac or dcen ac, dcep or dcen
E7028	Low hydrogen potassium, iron powder	H-fillets, F	ac or dcep
E7048	Low hydrogen potassium, iron powder	F, OH, H, V-down	ac or dcep

NOTES

Fusible inserts

A fusible insert is a pre-placed filler material that is fused to aid the formation of a weld made from one side only. They are mainly used on small bore pipework for the purpose of *controlling* root penetration. T.i.g. welding is used for fusing the inserts, usually without the use of a filler wire.



10
20
30
40
50
60
70
80
90
100

NOTES

Low alloy steel electrodes for m.m.a. welding

BS 2493

BS 2493 - *Low alloy steel electrodes for m.m.a. welding.*

This standard defines a range of m.m.a. electrodes which may be classified as low alloy and/or high strength.

The classification of an electrode to this standard is indicated by a code in the following order:

- a. **Composition code** - The chemical symbols Mn, Ni, Cr, Mo, W and V are used as appropriate to show the alloy additions. A prefixed figure is used to show the approximate percentage content of the first element defined. To indicate a low carbon version the letter *L* is added after the last chemical symbol.
- b. **Covering code** - The covering characteristic will be either basic, rutile or cellulosic and will be indicated by the letter B, R or C.
- c. **Hydrogen controlled electrodes** - The letter *H* is included if the electrode is capable of producing less than 15 ml H₂/100 g of weld metal deposited.

The specification defines the following grades of electrodes:

- d. Molybdenum steel electrodes, e.g. Mo C.
- e. Chromium-molybdenum steel electrodes, e.g. 12Cr Mo W V B.
- f. Nickel steel electrodes, e.g. 2Ni L B.
- g. Manganese-molybdenum steel electrodes, e.g. 2Mn Mo B.
- h. High strength low alloy steel electrodes, e.g. 2Ni Cr Mo B.

Note: Core wire may be made from rimming steel surrounded by a flux containing all the alloying elements required. Sometimes this results in thick coverings which can make positional welding difficult, in this case, an alloy steel core wire may be used in conjunction with a flux of normal thickness.

AWS A5.5-81

AWS A5.5-81 - *Specification for low alloy steel electrodes for SMAW.*

This code operates in a manner similar to the A5.1 but higher weld metal strengths in the range of 70-120 Kpsi are designated; the values and meanings of the next two numbers do not change. An additional chemical composition suffix is then added. Example classification: E9018-B3L.

The suffix used gives the following basic information.

- a. A - Carbon-molybdenum steel.
- b. B - Chromium-molybdenum steel.
- c. C - Nickel steel.
- d. NM - Nickel-molybdenum steel.
- e. D - Manganese-molybdenum steel.
- f. G - Requires a minimum value of one defined element, others to be agreed by purchaser/supplier.
- g. M - Conforms to military specifications.
- h. W - Specific copper content also defined.

a. to e. may follow the first suffix letter to further define the percentage of elements used. A final letter L indicates *low carbon* of 0.05% maximum content.

NOTES

Carbon and C-Mn steel tubular cored welding electrodes

BS 7084 - *Carbon and C-Mn steel tubular cored welding electrodes.*

When solid wires are used for welding, 100% of the gas shield has to be supplied from an external source. With *flux cored* wires, the electrode is tubular and contains minerals, deoxidisers, ferro-alloys and other additives, which together may form some or all of the gas required for shielding.

Welds can be produced at higher speeds, may be larger in size, will have improved contour and may have specific metallurgical qualities above and beyond the capabilities of solid wires irrespective of the type of gas shield used.

Electrodes—solid or flux cored—which require some additional external assistance in order to provide an effective gas shield must be used with electrode d.c. +ve; electrodes which are 100% self-shielding may be used with d.c. +ve or d.c. -ve polarity.

Wires and fluxes for submerged arc welding

BS 4165

The BS 4165 - *Electrode wires and fluxes for the s.a.w. of carbon steel and medium-tensile steel.*

This standard requires s.a.w. consumables to be tested using a multi-pass (M) or two pass (T) technique to an indicated minimum yield stress, e.g. 450 N/mm².

The chemical analysis is also controlled and this is shown by the suffix letter *S* and a number, e.g. 1, 2, 3 or 4.

The letter *S* indicates that a single (silicon) deoxidant is present, the numbers indicate the amount of manganese present as follows:

S1	C + 0.5 Mn	= silicon + carbon + 0.5% manganese
S2	C + 1.0 Mn	= silicon + carbon + 1.0% manganese
S3	C + 1.5 Mn	= silicon + carbon + 1.5% manganese
S4	C + 2.0 Mn	= silicon + carbon + 2.0% manganese

A second set of super deoxidised (*SD*) wires are classified which incorporate additional deoxidisers—usually aluminium, titanium and zirconium. These will produce very clean, fine grained steel deposits.

Code number examples:

S2 M 450

S1 T 300

SD3 M 450

Additional alloys may also be specified, for example:

SD1 2%Cr 0.5%Mo T450

AWS A5.17-89

AWS A5.17-89 - *Specification for carbon steel electrodes and fluxes for submerged arc welding.*

This specification states the requirements for the classification of carbon steel electrodes (both solid and composite) and fluxes for s.a.w.. The coding system shows the flux capabilities when combined with a specific electrode.

Example codings: F7A6-EM12K or F6A4-EC1 (trade name).

NOTES

This may be interpreted as follows:

- a. F - Indicates flux.
- b. 7 - Indicates the weld metal's minimum ultimate tensile strength in Kpsi x 10 when using the flux with the electrode identified.
- c. A - Designates the condition of heat treatment to the weld on which tests were conducted. A is for *as welded* and P for *PWHT*.
- d. 6 - Indicates the lowest temperature in °F x 10 at which a Charpy value of 27J was achieved.
- e. - - End of flux designation.
- f. E - E indicates a solid electrode. EC would indicate a composite electrode.
- g. M - This may be either L, M or H, indicating low, medium or high manganese content.
- h. 12 - This may be one or two digits and indicates the nominal carbon content of the electrode, e.g. 12 = 0.12%, 8 = 0.08% etc..
- i. K - Indicates the electrode is made from semi-killed steel.

Additional flux information

All fluxes to this specification must be of a granular nature and capable of flowing freely when used. Particle size is to be a matter of agreement between purchaser and supplier. The flux must permit the production of smooth beads with limited depth of undercut.

Fluxes are classified on the basis of mechanical properties of the weld metal they produce and therefore have to be shown in conjunction with the electrode used.

Fluxes used to this specification may contain fusible compounds of various proportions. Some fluxes contain deoxidisers, others do not, and fluxes may react differently with different electrodes and *arc voltage* used. A change of arc voltage during welding will change the amount of flux melted and may therefore change the composition of the weld metal. The effect of this change allows fluxes to be described as *neutral, active or alloy*.

Neutral fluxes are those which do not produce any significant change in the weld metal chemical analysis irrespective of arc voltage/arc length changes. Fluxes of this type contain little or no deoxidisers and rely on the electrode for deoxidation. They are mainly used for multi pass welds.

Active fluxes contain manganese and silicon as deoxidisers and the effect of these on the weld metal will change as the arc voltage changes, these fluxes are used mainly for single pass welds.

Alloy fluxes are those which can be used with a carbon steel electrode to produce a low alloy weld metal, as such, they come under the scope of AWS A5.23 - *Low alloy steel electrodes and fluxes for s.a.w.*

Additional wire information

The letter E stands for *solid electrode* to which a specific chemical analysis can be applied.

When the letters EC are applied, it indicates a composite electrode consisting of wire plus flux is to be used; this makes wire analysis meaningless and therefore the *weld metal* composition with a particular (separate) flux has to be determined. Because different manufacturers of flux cored/coated wires may use fluxes of various content, it is necessary to identify electrodes of this type by their trade name and enter this as part of the code.

NOTES

Welding plant is the general term given to the various pieces of electro-mechanical equipment that are needed to make welds. Gas apparatus is not included.

Welding plant ranges from simple transformers connected to tongs for MMA welding up to fully automatic submerged arc systems or robots, and it may be required to perform a number of functions:

1. Supply suitable current and voltage for the welding arc (power sources).
2. Conduct the current to the arc (cables, guns).
3. Feed the consumable into the arc (electrode holders, wire feeders, automatic welding heads).
4. Supply shielding gas to the arc if required (welding guns).
5. Guide the arc along the welding path at controlled speeds (automatic equipment, tractors, robots).

Power sources

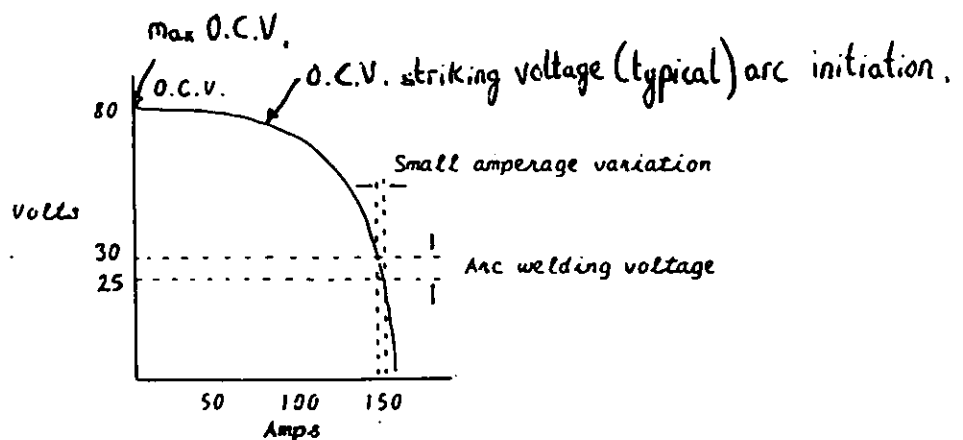
Welding arcs for most applications require current in the range of 30-500 A, and arc voltage (while running) of about 12-35 V. A welding process may require DC+ve, DC-ve, or AC, at essentially constant current (CC) or constant voltage (CV), and with steady or pulsed current. As electrical technology has become more sophisticated, process control has become more effective, and new types of power sources are now being introduced for most welding processes. An understanding of the electrical requirements of the various welding processes will make it easier to appreciate the features of new power sources, without requiring a knowledge of their internal technology.

The major division of welding processes is into those that require essentially constant current - MMA, TIG, plasma, and high current submerged arc welding, and those that require constant voltage welding - MIG/MAG, flux-cored, and lower current submerged arc welding. The fundamental current type required for those processes will not change, but we can expect significant changes in the technology of the welding plant required to run those processes.

or drooping characteristic

Constant current power sources for MMA and TIG welding

Stick electrodes operate at virtually constant current, and at arc voltages that are mainly characteristic of the type of flux coating. Electrodes may require AC, DC+ve, or DC-ve polarity. The simplest power sources are transformers with suitable means of controlling the current. DC output requires rectification of the output from a transformer. Output characteristics are shown below:



Carbon arc gouging also requires the use of CC power sources.

Required for MMA, TIG, Plasma arc and SAW > 1000 amps. W11-1

NOTES

Simple CC power sources can be used for MMA and TIG welding but with the exception of cheap hobby and DIY sets, on which the only control is for current, most industrial CC sets have special features to improve weld quality.

Special features - MMA

The voltage across the terminals of the power source, when no current is flowing is called the *open circuit voltage (OCV)*. Older sets had up to 90 OCV to ensure good arc striking, but safety restrictions have resulted in 50 OCV for many applications, but that has required a change in electrode formulations. Electrodes that give good penetration, such as cellulosic rods for pipe welding still require an OCV higher than 50 V.

Pipe welding electrodes also require power sources with output current that can be varied slightly with arc length, to allow welders to control penetration.

Some CC power sources provide a current boost at low arc voltages to prevent the rod from sticking in the pool when the arc becomes too short; this is called *arc force control*.

Special features - TIG

TIG welds can be started by scratching the tungsten on the workpiece but it is more desirable to use high-frequency (HF) arc ignition and for aluminium the HF is retained during welding to provide arc stability.

TIG welding of thin sheet is improved by pulsing the current at a frequency of about 0.3 Hz (one pulse every 3 seconds).

Aluminium and magnesium alloys require AC to avoid overheating of the tungsten electrode that would occur with DC+ve, while still providing sufficient cleaning action. The oxide films have a rectifying action which causes higher current to flow when the electrode is -ve. Many TIG sets allow the two halves of the cycle to be adjusted to balance the current and to give sufficient cleaning action without overheating the electrode.

Sine wave AC is now being replaced with square wave AC. This provides higher effective current and the rapid switching from one polarity to the other reduces the re-ignition time of the arc and makes it more stable.

Further modifications can be applied to the AC and DC current. The most sophisticated TIG sets provide control for the up-slope and down-slope of welding current, whether steady or pulsed.

Additional controls can provide pre-flow and post-flow of shielding gas to ensure purging of the weld zone before the arc ignites, and adequate coverage of the weld while it cools.

Constant current power sources for submerged arc welding

Heavy duty transformers and rectifiers, with capacities up to about 1500 A are available for submerged arc welding, and they are used in combination with wire feeders that run at speeds that are controlled by the arc voltage to maintain constant arc conditions. While welding, the feed speed does not stay constant, but the arc is regulated by variations in the wire feed speed to maintain constant arc voltage, and the output of the power source is essentially constant current. CC power is used for submerged arc welding at currents generally above about 1000 A, and when large weld pools are produced, as in surfacing applications.

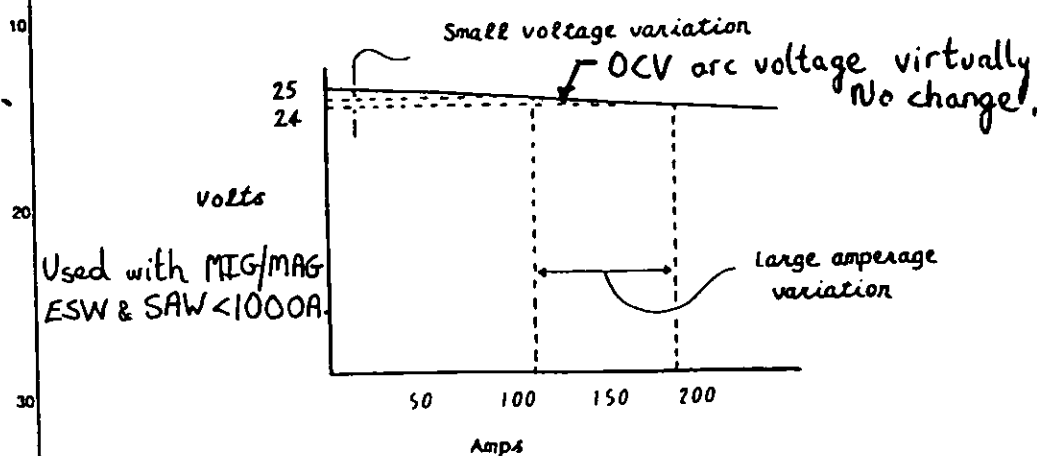
Constant voltage power sources

Constant voltage power sources must not be used for MMA or TIG welding because the short-circuit current is not limited and it can rise to very high values when striking an arc. In traditional CV power sources the mains frequency AC input is transformed to the desired voltage and current which is then fed to rectifiers and inductances. CV power sources must be used in combination with constant speed wire

NOTES

Note 1.

feeders. The output of CV power sources usually has a slope that causes a change of about 100 A in the current when a change in the resistance of the welding circuit causes a change of 1 V at the terminals. Output characteristics are shown below:



In CV systems, the arc is regulated by rapid changes in current which cause changes in the burn-off rate of the wire which is being fed at a constant speed into the arc. The arc voltage is maintained constant by the rapid changes in current as the electrode extension (*stick-out*) varies. Only constant stick-out will give constant current.

CV power source are available for currents in the range from about 50 A to 1500 A. Although many power sources have wide operating ranges, it should be remembered that they do not give the best control when used near their lower or upper limits.

All power sources for use up to about 200 A incorporate an inductance control which is a choke that slows down the rate of increase of the current during a short circuit. Control of inductance is important in dip transfer welding. High inductance leads to smoother transfer of each droplet after the short circuit, but if the inductance is too high, the arc stumbles when starting. Power source for use at high currents do not need inductance.

The essential controls on CV power sources are output voltage and inductance (up to about 200 A capacity).

Welding current is controlled by wire feed speed, and only if the feeder is not incorporated into the same chassis (as it is in *compact sets*). CV power sources themselves will not include a control for current.

Modifications of traditional CV power sources

The major modification of traditional CV power sources have been to give them multi-process capability by including CC output. A good multi-process set will be capable of MMA and MIG/MAG welding, and will incorporate control of inductance and arc force. Many modifications and new types of power sources are now being developed.

The first significant modification of CV power was the development of pulsed current. The early sets superimposed mains frequency or double mains frequency on the steady DC output and it was found that the interrupted spray transfer reduced spatter and extended the application of spray transfer to positional welding.

Further modifications, inverters, etc.

One of the disadvantages of high-current welding sets has been their size and weight, which arises mainly from the amount of copper and iron needed to deal with high currents in the transformer. Much effort has been devoted to reducing the size and weight of power sources, improving their electrical efficiency, making them more

NOTES

flexible in operation with more features to improve welding characteristics, and to making them cheaper.

Chronologically, the next major step was the development of power sources in which the mains AC input was first rectified to DC which was then inverted to high frequency AC which requires a relatively small transformer compared with mains frequency. The high frequency AC output from the transformer is rectified and controlled to provide the welding output.

Pulsing became more sophisticated and the development of semi-conductors that will carry welding currents and the use of microprocessor controls, has led to the recent introduction of power sources that are significantly different from what has been used in the past. The combination of inverter technology and new control systems has led to the introduction of power sources that are much smaller than before for the same output rating, and they are capable of many more functions. The broad capability of individual sets now makes their classification difficult, because many of them have CC and CV output, pulsing, etc, all in a chassis that might be about one quarter of the size of an older set with similar current capacity.

Inverter technology is used to reduce the size and weight of power sources, and it provides a convenient starting point to introduce other features to improve weld quality and ease of use.

Inverter sets are now available with the following types of output:

1. CC for MMA welding.
2. CC for TIG welding, with various additional features for pulsing, etc.
3. CC for plasma cutting.
4. CC/CV sets for multi-process welding.
5. CV for pulsed MIG/MAG welding.
6. Pre-programmed for MIG/MAG welding with various wire sizes, gases, materials, and pulsing.
7. Pulse wave forms for all types of welding, for which the wave forms can be pre-programmed or entered with computers.

Wire feeders

The function of a wire feeder are:

- To push the wire to the arc at a controlled speed, regardless of changes in cable configuration, wire quality, etc.
- To feed shielding gas and water to the gun.
- To control additional features, such as burn-back.

The essential parts of a wire feeder are:

- a. The drive motor and gear box.
- b. Controls that might include tachometer feedback for speed control during welding, inching speed, burn-back timer, spot welding timer, etc.
- c. Inlet guides, feed rolls with pressure adjustment, outlet guides.
- d. Gas solenoid.

NOTES

Welding heads, guns, and torches

These terms are generally used to indicate the devices that feed the current, wire, and shielding gas to the arc. In semiautomatic welding, if a wire is fed through the device it is called a *gun*, and it is a *torch* if only gas passes through it. Heads, guns, and torches can be water cooled for high welding currents.

Welding heads are fitted to automatic machines, and are for submerged arc (to feed wire and flux), MIG/MAG and FCAW (to feed wire and gas), and TIG, or plasma welding (shielding gas only). Separate feeders and heads can be attached to TIG and plasma heads for adding filler metal.

The devices are rated for maximum welding current. For submerged arc welding a 100% duty cycle rating is necessary. Most MIG/MAG gun/cable combinations are rated for 60% duty cycle, when using CO₂ shielding gas. For argon-rich gases, which put a heavy heat load on the gun, the maximum current that should be used may be as low as about a half of the CO₂ rating.

For welder comfort, most MIG/MAG guns deliver the wire at an angle of about 60° with the handle axis, but for overhead welding straight guns are more comfortable.

The welding electrode wire is pushed through the cable via a steel spring liner to the gun, where it passes through the neck and into the contact tube (tip) where it leaves the gun to enter the arc. The gun and cable should be cleaned regularly to remove debris from the wire, and the contact tip should be replaced when it is worn. If the wire causes feeding problems, and the system is in good condition, the wire should be returned to the supplier and replaced.

Aluminium wire (which is very soft compared with steel) requires a plastic cable liner and the elimination of all rough edges where it may become scored.

MIG/MAG cables usually contain the liner for the electrode wire, the gas hose, water hoses if used, trigger switch leads, and the copper cable to conduct the welding current.

TIG torches come in a wide variety of shapes to suit different applications, and they are rated for maximum current at 100% duty cycle.

TIG cables include gas hoses, water hoses, and trigger switch leads.

Gas cups (nozzles) for MIG/MAG guns, and the flux cones for submerged arc welding are made from copper. TIG nozzles are usually ceramic.

Before starting a job, guns and torches should be checked to determine if they are adequate for the welding current to be used. Guns, contact tips, gas nozzles, and cables should be routinely checked for damage and clogging, and worn or damaged parts should be replaced to ensure good performance.

Control units

Control units for automatic welding usually contain all the functions of a wire feeder plus extra features for control of weld striking, welding, crater filling and burn-back, timers for those parts of a welding cycle, arc voltage, and auxiliary equipment, such as positioners, rotators, etc. and a wire straightener is generally included. For automatic welding the welding head is often mounted directly on the control unit and wire feeder so that the straight wire is fed into the arc, thereby assisting its placement during welding.

NOTES

Mechanised, automatic, and robotic welding

Considerable gains in productivity and quality can be achieved by the use of machines that control the position and speed of the arc along the welding path. It becomes very difficult for a welder to maintain good weld quality at travel speeds faster than about 500 mm/min, but submerged arc, MIG/MAG and flux-cored welding are capable of producing good weld quality at speeds to as much as 5000 mm/min, and deposition rates are much higher. The continuous wire processes can be mechanised and automated to various extents that depend on factors such as the size and number of components to be produced.

Small mechanised equipment

Productivity and quality can be improved by the use of small equipment that will control the position and speed of the arc. A range of tractors is available for making filler and groove welds, and for surfacing. Self-guiding units that sit on horizontal plate are used widely in deck welding. All-position tractors are mounted on rails that are attached to the surface of the workpiece.

Additional units can be mounted on the tractors to provide weaving motion.

Tractors may provide motion only for semi-automatic welding systems, in which the remainder of the equipment will be the same as for manual welding, or the tractor may include its own welding control unit, wire feeder, travel control unit, flux hopper, etc. and be capable of carrying currents of over 1000 A.

Large mechanised equipment

The mechanised welding of large components, such as pressure vessels, utilises rotators, positioners, columns and booms, and other more specialised units to provide the controlled relative motion of the workpiece and the welding head.

Small adjustments of the position of the arc may be made by the operator or by automatic sensors that control the position of the head.

Automatic welding

Many repetitive parts are welded in machines that are loaded by an operator who merely presses a button to start a complete automatic cycle the positions the part under the welding head, runs through a welding sequence, and positions the part for unloading.

Robotic welding

Robotic welding is similar to automatic welding, except that welding robots are capable of manipulation of torch and work piece, allowing welding of components with irregular weld paths. Because the removal of slag would create problems, most robots use gas-shielded MIG/MAG solid wires or metal-cored wires. Most robots are programmed by steering the welding head around the weld path and entering that path into the robot's memory. The robot controller also feeds signals for controlling wire feed speed, arc voltage, the various weld sequences, and automatic cleaning of the gas nozzle.

NOTES

BS 499 : Part 2 : *Symbols for welding* specifies requirements for the symbolic representation of welds on drawings for common types of welds.

Elementary symbols

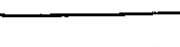
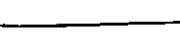
Each weld may be characterized by a symbol which, in general, is representative of the shape of the weld to be made, or the edge preparation to be used, e.g. single-vee butt weld. An *elementary symbol* does not indicate the welding process to be used.

Detail regarding root gap, use of backing material, and number of runs to be deposited will be given on the welding procedure sheet.

The vertical line on the symbols for single-bevel butt, single-J butt and fillet welds must always be placed on the left hand side of the symbol irrespective of the orientation of the weld metal.

Providing the joint is not too complex, combinations of elementary symbols are used for welds made from two sides and compound welds, e.g. a fillet weld superimposed on a single bevel butt weld.

Table 1. Elementary symbols BS 499 : Part 2 : 1980

No.	Designation	Illustration	Symbol
1	Butt weld between flanged plates* (the flanges being melted down completely)		∩
2	Square butt weld ¹		
3	Single-V butt weld		∇
4	Single-bevel butt weld		✓
5	Single-V butt weld with broad root face		Y
6	Single-bevel butt weld with broad root face		Y
7	Single-U butt weld		U
8	Single-J butt weld		J
9	Backing or sealing run		⌒

* Butt welds between flanged plates (symbol 1) not completely penetrated are symbolized as square butt welds (symbol 2) with the weld thicknesses shown (see table 101)

¹ This symbol is used to indicate a stud weld when there is no end preparation and no filler metal

NOTES

Table 1. (concluded)

no.	Description	Illustration	Symbol
10	Fillet weld		
11	Plug weld (circular or elongated hole, completely filled)		
12	Spot weld (resistance or arc welding) or projection weld	 	
13	Seam weld		

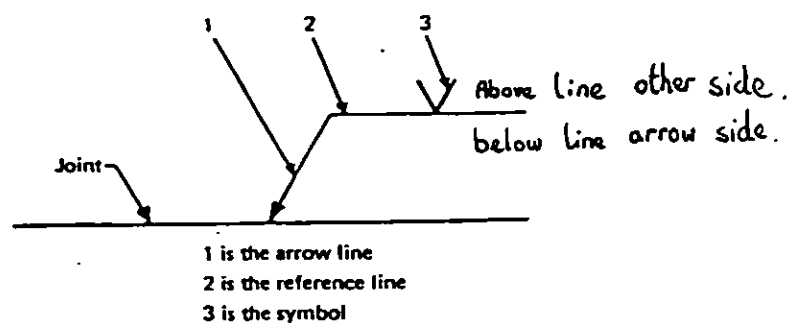
Supplementary symbols

Supplementary symbols may be used when a specific external weld profile is required. They are used in conjunction with the relevant elementary symbol.

Shape of weld surface	Symbol
(a) flat (usually finished flush)	
(b) convex	
(c) concave	

Position of symbols

The symbols are used in conjunction with an *arrow line* and a *reference line*.



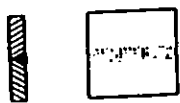
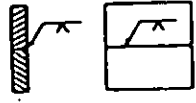
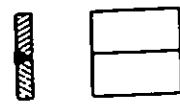
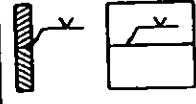
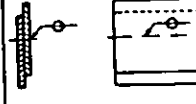
The position of a weld in a particular joint relative to the parts being joined is indicated by the *head* of an arrow, this denotes the *reference side* of the joint. The side nearer the arrow head is known as the *arrow side*; the remote side is known as the *other side*.

NOTES

The position of the arrow line with respect to the weld is of no significance, except in the case of joints in which only one part is prepared, in this case, the arrow must point towards that part.

The symbol positioning relative to the *reference line* is shown in the following table:

Table 4. Position of the symbol*

Illustration	Graphic representation	Symbolic representation	Description of position
			Below the reference line if the external surface of the weld (weld face) is on the arrow side of the joint.
			Above the reference line if the external surface of the weld (weld face) is on the other side of the joint.
			Across the reference line in the case of welds made within the plane of the joint

*3rd angle projection

Dimensions

Any dimension relating to the cross-section of the weld must be given on the left hand side of the symbol; longitudinal dimensions must be given on the right hand side of the symbol; distances between adjacent weld elements must be indicated in parenthesis.

Butt welds are intended to be continuous and have full penetration along the entire length of the joint, unless dimensional detail specifies otherwise.

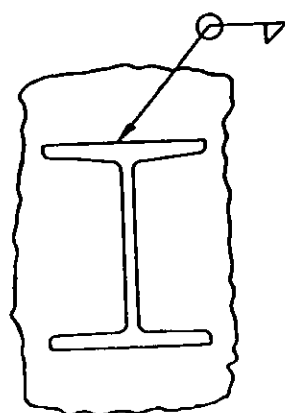
Fillet welds are intended to be continuous along the entire length of the joint, unless dimensional detail specifies otherwise. The cross sectional dimension indicated for a fillet weld is referring to the leg length. When it is also desired to indicate the design throat thickness, then the leg length dimension is prefixed with the letter *b*; the design throat thickness dimension is prefixed with the letter *a*.

NOTES

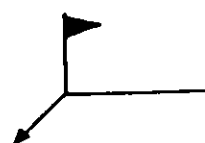
Complementary indications

Complimentary indications apply to the following:

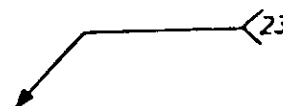
- a peripheral weld—a weld all round a joint,
- a site weld—not a shop weld,
- non-destructive testing—other than visual examination,
- welding process—information regarding the welding process to be used is given on the welding procedure sheet. When it is also desired to indicate the process as part of the symbolic representation, the appropriate process number given in BS 499 is placed within a *fork* at the end of the reference line.



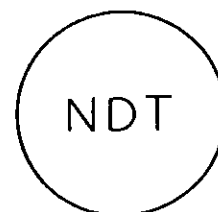
Use of symbol for peripheral welds



Use of symbol for site welds



Example of the indication of process



Symbol for non-destructive testing

SYMBOLS INDICATE THE PREPARATION OF PLATES			WELD SURFACE		SIGNIFICANCE OF THE ARROW AND POSITION OF WELD SYMBOL
TYPE OF WELD	ILLUSTRATION	SYMBOL	SHAPE OF SURFACE	SYMBOL	
FILLET WELD			FLAT (USUALLY FINISHED FLUSH)		 SYMBOLS BELOW REFERENCE LINE = WELD ON ARROW SIDE
SQUARE BUTT			CONVEX		
SINGLE 'V' BUTT			CONCAVE		
SINGLE BEVEL BUTT			EXAMPLES OF APPLICATION		 SYMBOLS ABOVE REFERENCE LINE = WELD ON OTHER SIDE
SINGLE 'V' BUTT WITH BROAD ROOT FACE			SECTION	SYMBOL	
SINGLE BEVEL BUTT WITH BROAD ROOT FACE			 FLAT (FLUSH) SINGLE 'V' BUTT	 FLAT (FLUSH) SINGLE 'V' BUTT	
SINGLE 'U' BUTT			 CONVEX DOUBLE 'V' BUTT	 CONVEX DOUBLE 'V' BUTT	 SYMBOLS ABOVE & BELOW REF. LINE = WELD ON BOTH SIDES
SINGLE 'J' BUTT			 CONCAVE FILLET WELD	 CONCAVE FILLET WELD	
BUTT WELD BETWEEN FLANGED PLATES (FLANGES HELD TOGETHER COMPLETELY)			FLAT (FLUSH) SINGLE 'V' BUTT with FLAT (FLUSH) BACKING RUN		
SEALING RUN (MADE WITH SINGLE 'V' BUTT)			ADDITIONAL SYMBOLS		 INTERMITTENT FILLET WELDS
PLUG WELD			 WELD ALL ROUND		
SPOT WELD			 WELD ON SITE		
SEAM WELD					

WELD SYMBOLS AND THEIR USES

10 B.S. 499: Pt 2 1962

Table 5. (concluded)

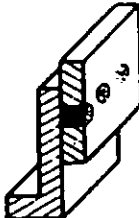
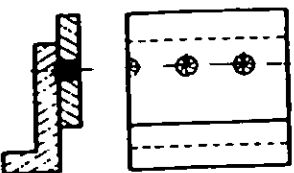
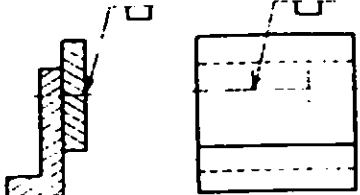
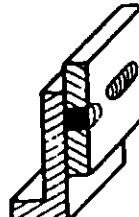
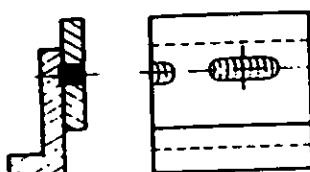
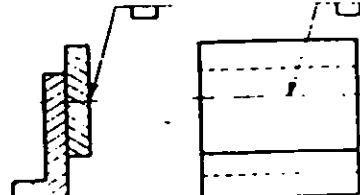
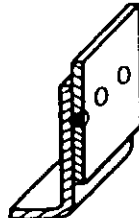
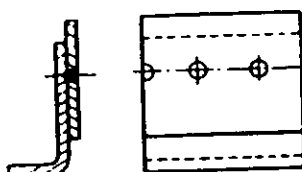
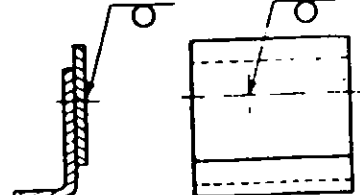
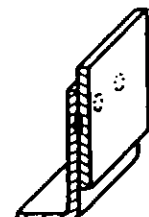
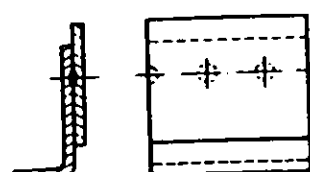
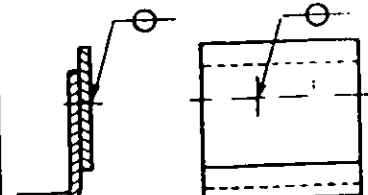
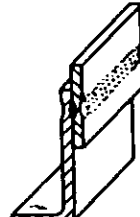
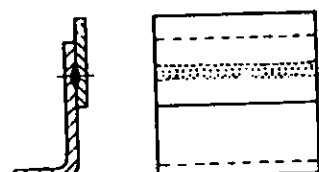
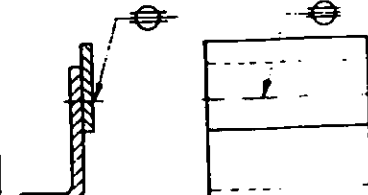
No.	Designation symbol (numbers refer to table 11)	Illustration	Graphic representation	Symbolic representation
22	Plug weld 			
23	11			
24	Spot weld 			
25	12			
26	Seam weld 			

Table 6. Examples of combinations of elementary symbols

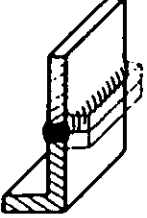
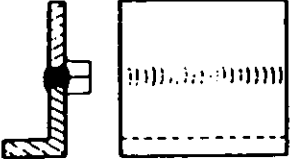
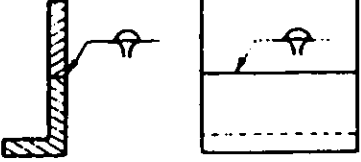
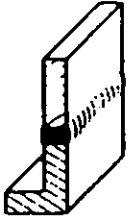
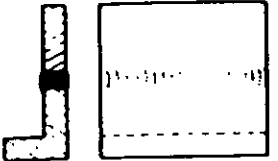
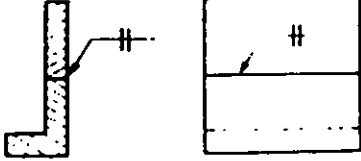
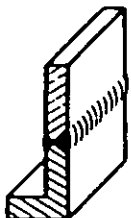
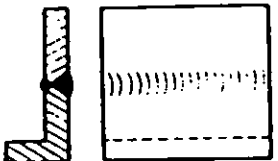
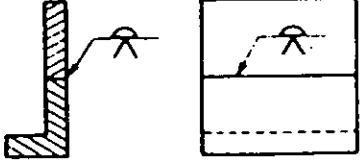
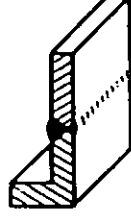
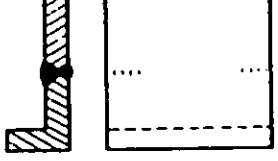
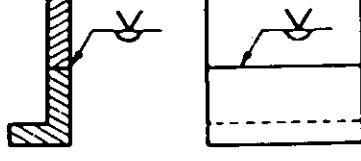
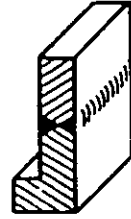
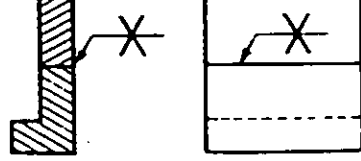
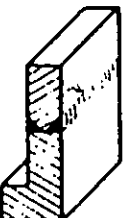
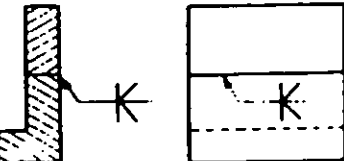
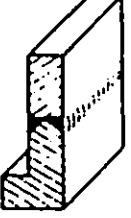
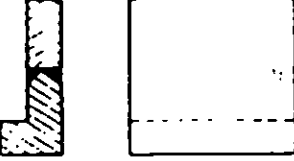
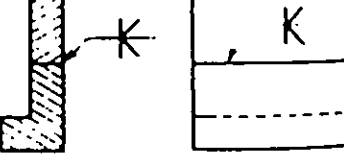
No	Designation symbol (numbers refer to table 1)	Illustration	Graphic representation	Symbolic representation
1	Butt weld between flanged plates 1 and backing run 9 1 - 9			
2	Square butt weld 2 welded from both sides 2 - 2			
3	Single-V butt weld 3 and backing run 9 3 - 9			
4	Single-V butt weld 3 and backing run 9 3 - 9			
5	Double-V butt weld 3 (X weld) 3 - 3			
6	Double bevel butt weld 4 (K weld) 4 - 4			
7	Double bevel butt weld 4 (K weld) 4 - 4			

Table 6. (concluded)

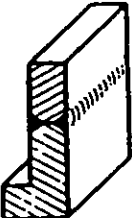
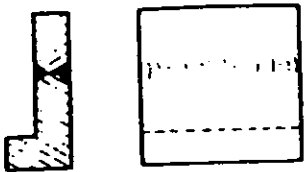
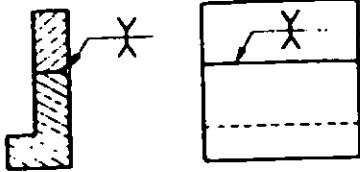
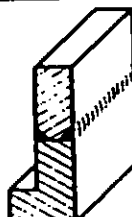
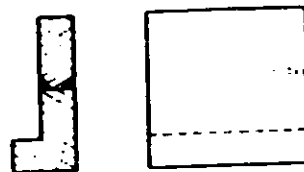
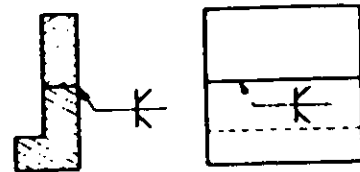
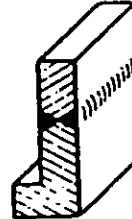
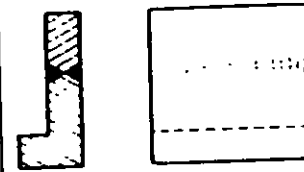
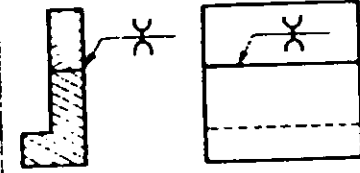
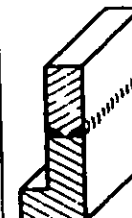
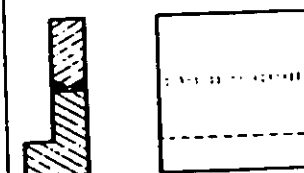
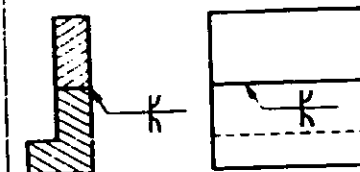
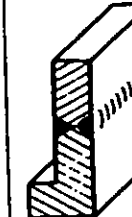
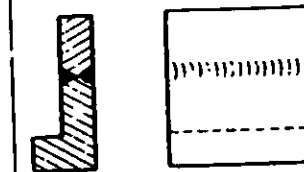
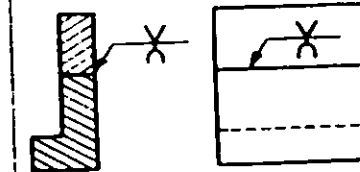
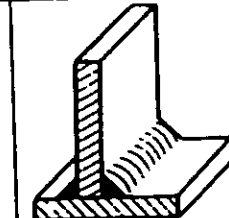
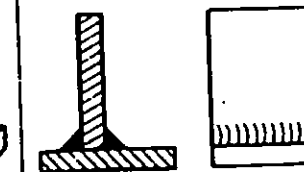
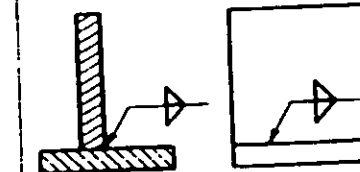
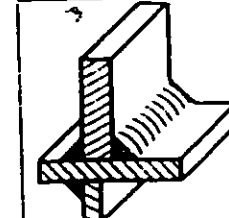
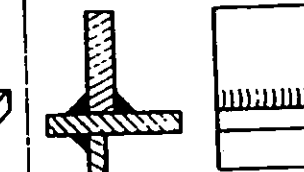
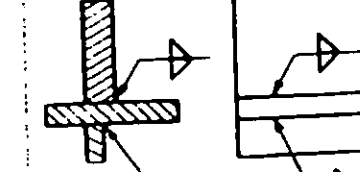
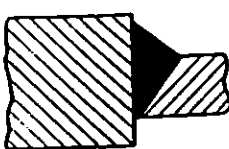
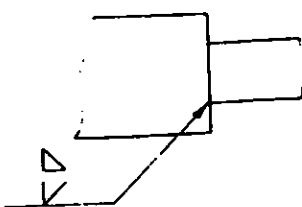
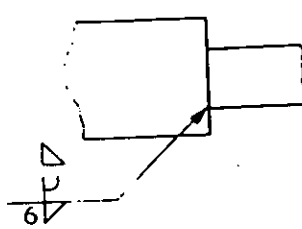
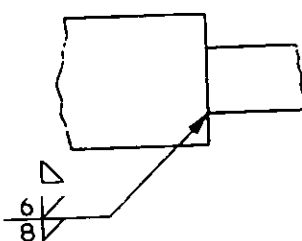
No	Designation symbol (numbers refer to table 1)	Illustration	Graphic representation	Symbolic representation
8	Double-V butt weld with broad root face  5 5 - 5			
9	Double-bevel butt weld with broad root face  6 6 - 6			
10	Double-U butt weld  7 7 - 7			
11	Double-J butt weld  8 8 - 8			
12	Single-V butt weld and single-U butt weld  3  7 3 - 7			
13	Fillet weld  10			
14	and fillet weld  10 10 - 10			

Table 7. Examples of use of symbols for compound welds

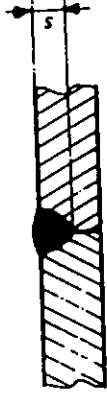
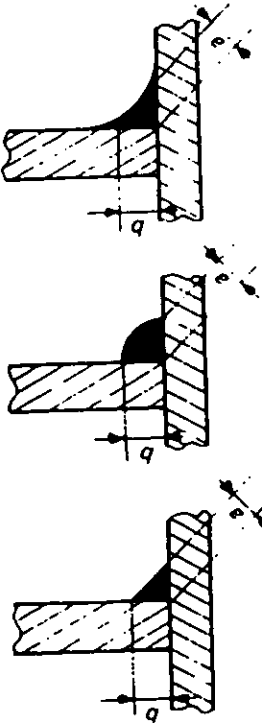
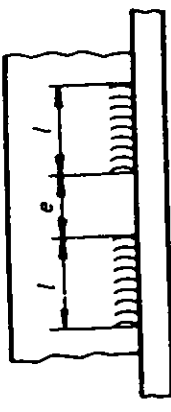
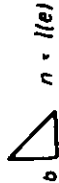
Designation symbol (numbers refer to table 1)	Graphic representation	Symbolic representation
Single-bevel butt weld with fillet weld superimposed  4  10 4 + 10		
Single-J butt weld with fillet weld superimposed  8  10 and with fillet weld on root side  10 8 + 10 - 10		
Partial penetration single-bevel butt weld with fillet weld superimposed  4  10 and with fillet weld on arrow side  10 4 + 10 - 10		

* If dimensional requirements see table 9.

Table 8. Examples of combinations of elementary and supplementary symbols

No.	Symbol	Illustration	Graphical representation	Symbolic representation
1				
2				
3				
4				
5				
6				
7				

Table 3. Main dimensions

No.	Designation of welds	Definition	Inscription
1	Butt weld		 (see 5.2)
			 (see 5.2)
			 (see 5.2)
2	Butt weld between plates with raised edges		 (see 5.2)
3	Continuous fillet weld		  (see 5.3)
4	Intermittent fillet weld		  (see 5.3)

AMERICAN WELDING SOCIETY

Basic Welding Symbols and Their Location Significance									
Location significance	Fillet	Plug or Slot	Spot or Projection	Stud	Seam	Back or Backing	Surfacing	Flange Corner	Flange Edge
Arrow Side									
Other Side				Not used			Not used		
Both Sides		Not used	Not used	Not used	Not used	Not used	Not used	Not used	Not used
No Arrow Side or Other Side Significance	Not used	Not used		Not used		Not used	Not used	Not used	Not used
Location Significance	Groove							Scar for Brazed Joint	
	Square	V	Bevel	U	J	Flare-V	Flare-Bevel		
Arrow Side									
Other Side									
Both Sides									
No Arrow Side or Other Side Significance		Not used	Not used	Not used	Not used	Not used	Not used	Not used	

Supplementary Symbols								Location of Elements of a Welding Symbol									
Weld-All Around	Field Weld	Melt-Thru	Consumable Insert	Backing Spacer	Contour												
					Flush	Convex	Concave										
Basic Joints																	
Identification of Arrow Side and Other Side of Joint																	
Butt Joint				Corner Joint													
T-Joint				Lap Joint													
				Edge Joint													
				Process Abbreviations													
				Where process abbreviations are to be included in the tail of the welding symbol, reference is made to Table 1. Designation of Welding and Allied Processes by Letters, of AWS A2.4-86 AMERICAN WELDING SOCIETY, INC. 550 N W LeJeune Rd., Miami, Florida 33126													

STANDARD WELDING SYMBOLS

Typical Welding Symbols		
Double-Fillet Welding Symbol Weld size Length Omission indicates that weld extends between abrupt changes in direction or as dimensioned	Chain Intermittant Fillet Welding Symbol Pitch (distance between centers) of increments Size (length of leg) Length of increments	Staggered Intermittant Fillet Welding Symbol Pitch (distance between centers) of increments Size (length of leg) Length of increments
Plug Welding Symbol Include angle of countersink Size (diameter of hole at root) Pitch (distance between centers) Depth of filling in inches (omission indicates filling is complete)	Back Welding Symbol Back weld 2nd operation 1st operation	Backing Welding Symbol Backing weld 1st operation 2nd operation
Spot Welding Symbol Size or strength Number of welds Pitch RSW Process	Stud Welding Symbol Size Pitch Number of studs	Seam Welding Symbol Size or strength Increment length Pitch RSEW Process
Square-Groove Welding Symbol Weld size Root opening	Single-V Groove Welding Symbol Depth of preparation Weld size Root opening Groove angle	Double-Bevel-Groove Welding Symbol Weld size Root opening Arrow points toward member to be prepared
Symbol with Backgouging Depth of preparation Weld size Back gouge	Flare-V Groove Welding Symbol Weld size	Flare-Bevel-Groove Welding Symbol Weld size
Multiple Reference Lines 1st operation on line nearest arrow 2nd operation 3rd operation	Complete Penetration Indicates complete penetration regardless of type of weld or joint preparation CJP	Edge Flange Welding Symbol Radius Weld size Height above point of tangency
Flash or Upset Welding Symbol Process reference FW	Melt-Thru Symbol Weld size	Joint with Backing R R indicates backing removed after welding
Joint with Spacer With modified groove weld symbol	Flush Contour Symbol 	Convex Contour Symbol
Double bevel groove 		

*It should be understood that these charts are intended only as shop aids. The only complete and official presentation of the standard welding symbols is in A2.4.

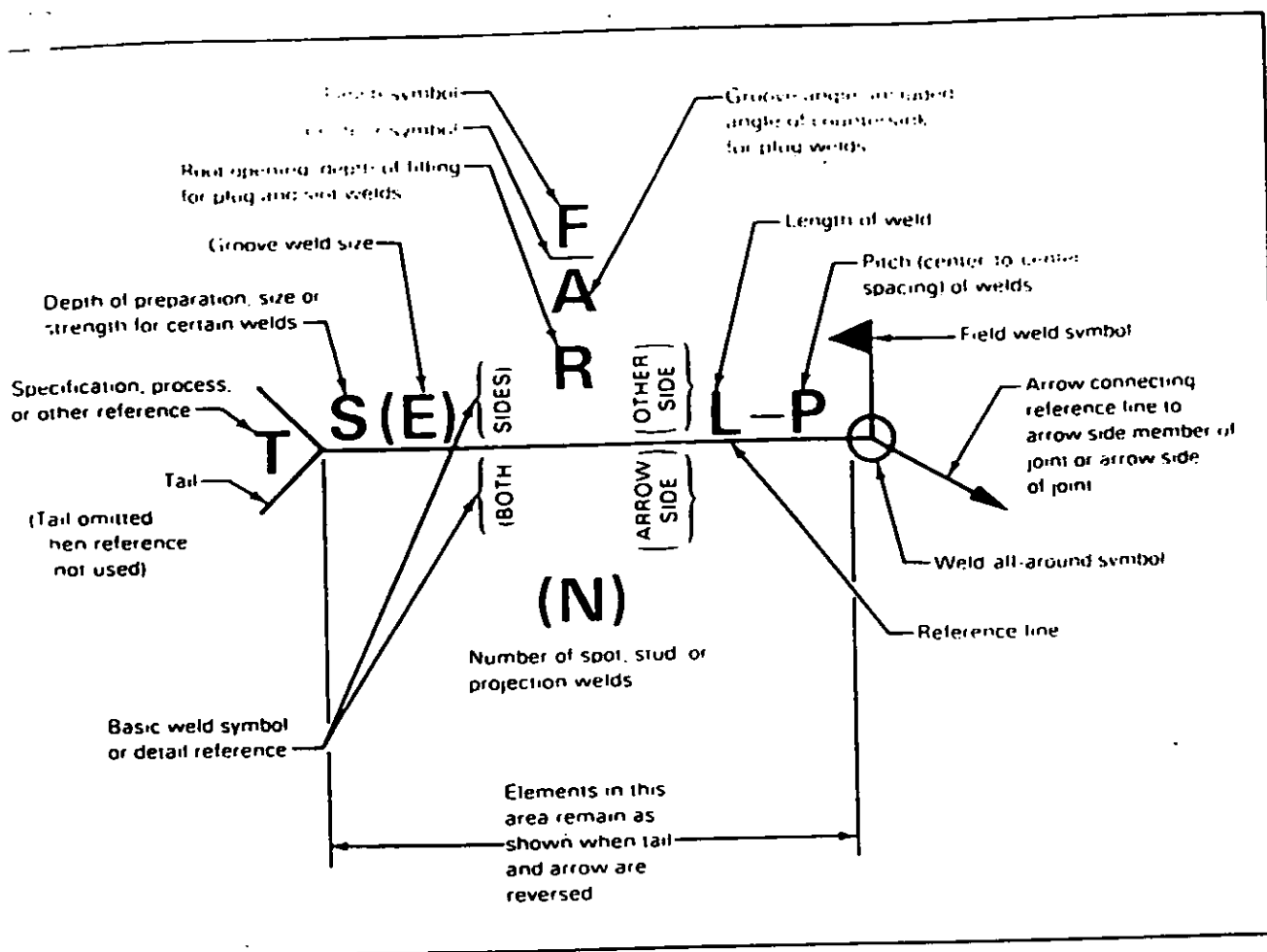
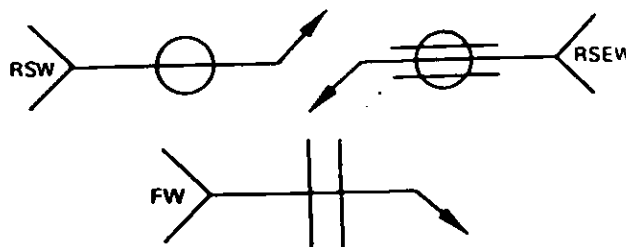


Figure 3—Standard Location of Elements of a Welding Symbol

3.1.1 Fillet, Groove, and Flange Weld Symbols. For these symbols, the arrow shall connect the welding symbol reference line to one side of the joint, and this side shall be considered the arrow side of the joint. The side opposite the arrow side of the joint shall be considered the other side of the joint (see Figure 5).

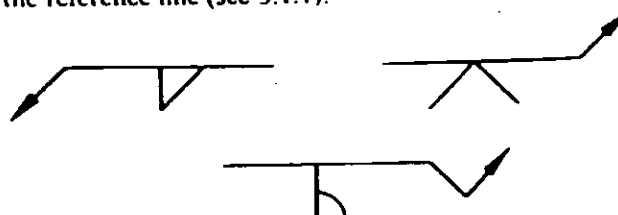
3.1.2 Plug, Slot, Spot, Projection and Seam Weld Symbols. For these symbols, the arrow shall connect the welding symbol reference line to the outer surface of one of the joint members at the center line of the desired weld. The member toward which the arrow points shall be considered the arrow side member. The other joint member shall be considered the other side member (see figures cited in sections 6 to 9 inclusive).

1.3 Symbols with No Side Significance. Some weld symbols have no arrow side or other side significance, although supplementary symbols used in conjunction with them may have such significance (see 8.1.2, 8.1.4, and Tables 1 and 2).

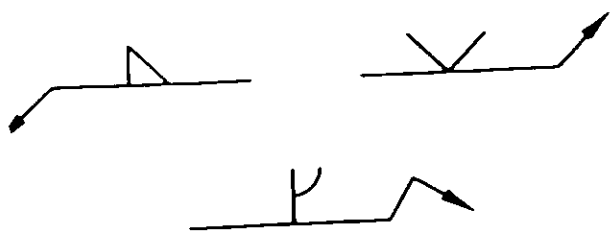


3.2 Location of Weld With Respect to Joint

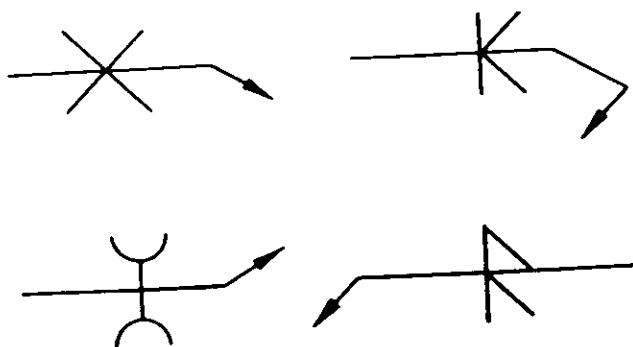
3.2.1 Arrow Side. Welds on the arrow side of the joint shall be specified by placing the weld symbol below the reference line (see 3.1.1).



3.2.2 Other Side. Welds on the other side of the joint shall be specified by placing the weld symbol above the reference line (see 3.1.1).

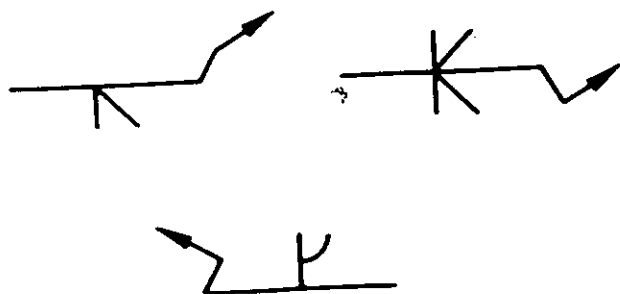


3.2.3 Both Sides. Welds on both sides of the joint shall be specified by placing weld symbols both below and above the reference line (see 3.1.1).



3.3 Orientation of Specific Weld Symbols. Fillet, bevel-groove, J-groove, flare-bevel-groove, and corner-flange weld symbols shall be drawn with the perpendicular leg always to the left.

3.4 Break in Arrow. When only one member of a joint is to be prepared, the arrow shall have a break, and point toward that member (see Figure 6). If it is obvious which member is to be prepared or there is no preference as to which member is to be prepared, the arrow need not be broken.

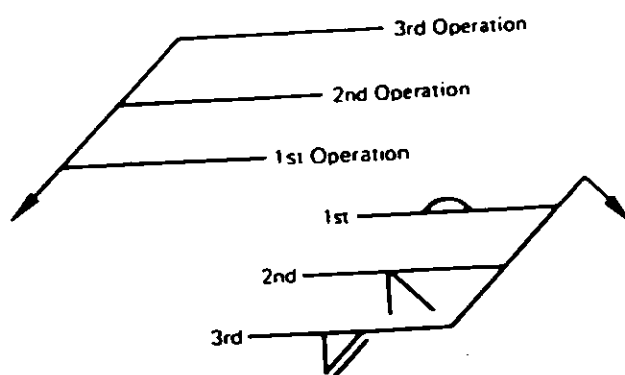


3.5 Combined Weld Symbols. For joints requiring more than one weld type, a symbol shall be used to specify each weld (see Figure 7).

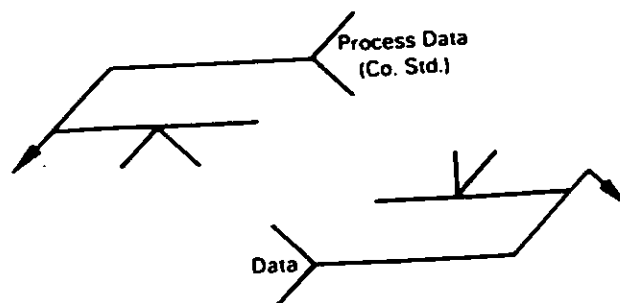


3.6 Multiple Reference Lines

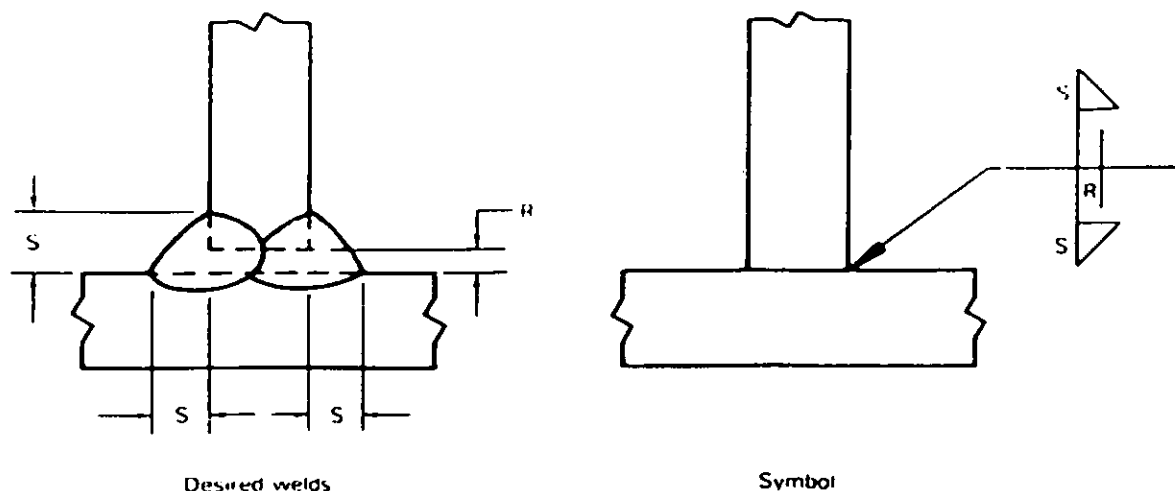
3.6.1 Sequence of Operations. Two or more reference lines may be used to indicate a sequence of operations. The first operation is specified on the reference line nearest the arrow. Subsequent operations are specified sequentially on other reference lines.



3.6.2 Supplementary Data. The tail of additional reference lines may be used to specify data supplementary to welding symbol information.



3.6.3 Examination Information. Examination information may be shown on an additional reference line, as described in Part C, or in the tail.

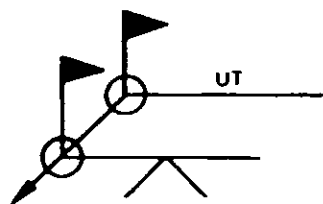


(D) Double square-groove with double fillet welds

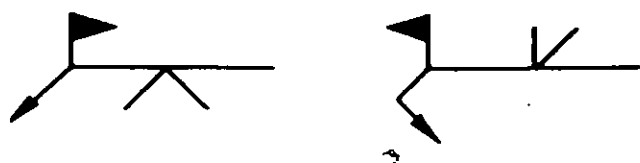
Figure 7 (continued) — Combination of Weld Symbols

3.6.4 Field Weld and Weld All-Around Symbols.

When required, the weld- (or examine-) all-around symbol shall be placed at the junction of the arrow line and reference line for each operation to which it is applicable. The field weld symbol may also be applied to the same location.



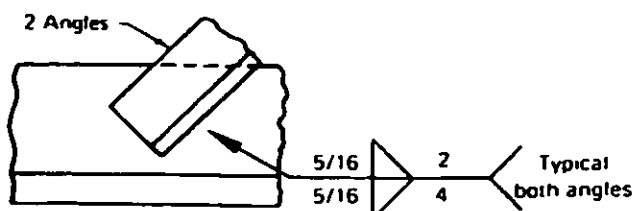
3.7 Field Weld Symbol. Field welds (welds not made in a shop or at the place of initial construction) shall be specified by adding the field weld symbol. The flag shall be placed above and at a right angle to the reference line at the junction with the arrow.

**3.8 Extent of Welding Denoted by Symbols**

3.8.1 Weld Continuity. Unless otherwise indicated, all welds shall be continuous and of user's standard proportions.

3.8.2 Changes in the Direction of Welding. Symbols only apply between any changes in the direction of welding, or to the extent of hatching or dimension lines (see Figure 8), except when the weld-all-around symbol is used [see Figure 9(B), (C), (D), and (E)]. Additional welding symbols or multiple arrows shall be used to specify the welds required for any changes in direction. When it is desirable to use multiple arrows on a welding symbol, the arrows shall originate from a single reference line [see Figure 9(A)] or from the first reference line in the case of a multiple reference line symbol.

3.8.3. Hidden Members. When the welding of a hidden member is the same as that of a visible member, it may be specified as shown below. If the welding of a hidden member is different from that of a visible member, specific information for the welding of both shall be specified. If needed for clarification, auxiliary illustrations or views shall be provided.



3.8.4 Weld Location Not Specified. A weld, with a length less than the available joint length and not critical

regarding location, may be specified without indicating the location as shown in Figure 8(F)(1).

3.8.5 Weld Location Specified. A weld, with a length less than the available joint length whose location is significant, shall have the location specified on the drawing [see Figure 8(C)].

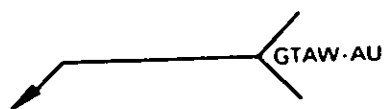
3.9 Weld-All-Around Symbol

3.9.1 Welds in Multiple Directions or Planes. A continuous weld, whether single or combined type, extending around a series of connected joints may be specified by the addition of the weld-all-around symbol at the junction of the arrow and reference line. The series of joints may involve different directions and may lie in more than one plane [see Figure 9(B), (C), (D), and (E)].

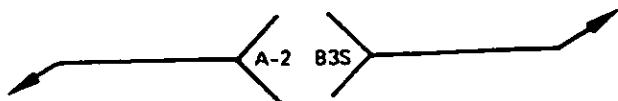
3.9.2 Circumferential Welds. Welds extending around the circumference of a pipe are excluded from the requirement regarding changes in direction and do not require the weld-all-around symbol to specify a continuous weld.

3.10 Tail of the Welding Symbol

3.10.1 Welding and Allied Process Specification. The welding and allied process to be used may be specified by placing the appropriate letter designations from Table 1 or Table 2 in the tail of the welding symbol. An auxiliary suffix from Table 3 may be used. (Tables are at the end of text.)

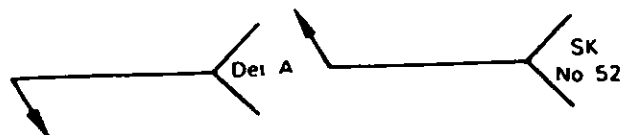


3.10.2 References. Specifications, Codes or any other applicable documents may be specified by placing the reference in the tail of the welding symbol. Information contained in the referenced document need not be repeated in the welding symbol.

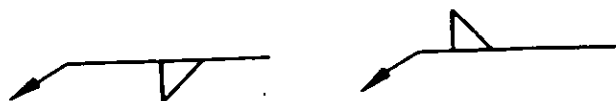


3.10.3 Welding Symbols Designated "TYPICAL". Repetitions of identical welding symbols on a drawing may be avoided by designating a single welding symbol as typical and pointing the arrow to the representative joint. The user shall provide additional information to completely identify all applicable joints.

3.10.4 Designation of Special Types of Welds. When the basic weld symbols are inadequate to indicate the desired weld, the weld shall be specified by a cross section, detail, or other data with a reference thereto in the tail of the welding symbol. This may be necessary for skewed joints (see 4.11 and 5.7).



3.10.5 Omission of Tail. When no references are required, the tail may be omitted from the welding symbol.



3.10.6 Drawing Notes. Drawing notes may be used to provide information pertaining to the welds. Such information need not be repeated in the welding symbols.

3.11 Contours Obtained by Welding. Welds to be made with approximately flush, flat, convex, or concave contours without the use of mechanical finishing shall be specified by adding the flush, flat, convex, or contour symbol to the weld symbol.

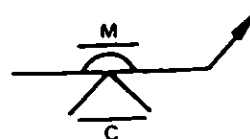
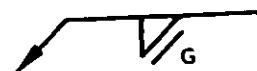
3.12 Finishing of Welds

3.12.1 Contours Obtained by Finishing. Welds to be mechanically finished approximately flush, flat, convex, or concave shall be specified by adding both the appropriate contour and the finishing symbol.

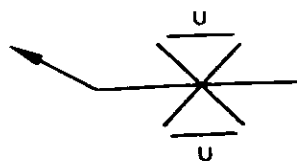
3.12.2 Finishing Methods. The following finishing symbols may be used to specify the method of finishing, but not the degree of finish:

Mechanical Methods:

- C — Chipping
- G — Grinding
- H — Hammering
- M — Machining
- R — Rolling



3.2.3 Finishing Method Unspecified. Welds to be finished approximately flush, flat, convex, or concave if the method unspecified shall be indicated by adding the letter "F" to the appropriate contour symbol.



3.1 Melt-Through Symbol. The melt-through symbol shall be used only when complete root penetration plus 5/16" root reinforcement is required in welds made from one side (see Figure 10).

3.13.1 Melt-Through Symbol Location. The melt-through symbol shall be placed on the side of the reference line opposite the weld symbol (see Figure 10).

3.13.2 Melt-Through Dimensions. The height of root reinforcement may be specified by placing the required dimension to the left of the melt-through symbol (see Figure 10). The height of root reinforcement may be unspecified.

3.4 Melt-Through with Flange Welds

3.14.1 Melt-Through With Edge-Flange Welds. Edge-flange welds requiring complete joint penetration shall be specified by the edge-flange weld symbol with the melt-through symbol placed on the opposite side of the reference line. The same welding symbol is used for joints either detailed or not detailed on the drawing (see Figure 10).

3.14.2 Melt-Through With Corner-Flange Welds. Corner-flange welds requiring complete joint penetration shall be specified by the corner-flange weld symbol with the melt-through symbol placed on the opposite side of the reference line. A broken arrow shall point to the member to be flanged where the joint does not give this information (see Figure 10).

3.15 Method of Drawing Symbols. Symbols may be drawn mechanically or freehand. Symbols intended to appear in publications or to be of high precision should be drawn with dimensions and proportions given in Appendix A.

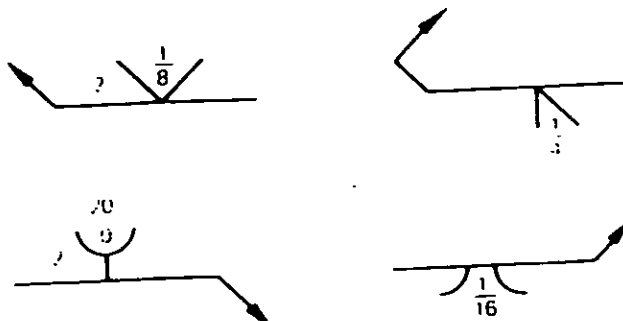
3.16 U.S. Customary and Metric Units. The same system that is the standard for the drawings shall be used on welding symbols. Dual units shall not be used on welding symbols. If it is desired to show conversions from metric to U.S. customary, or vice versa, a table of conversions

may be included on the drawing. For guidance in drafting standards, reference is made to the *ANSI Y14.1 Drafting Manual*. For guidance on the use of metric (SI) units reference is made to *AWS A11.1 Metric Practice Guide for the Welding Industry*.

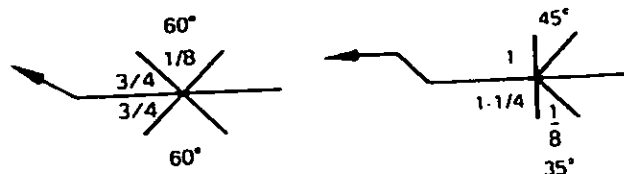
4. Groove Welds

4.1 General

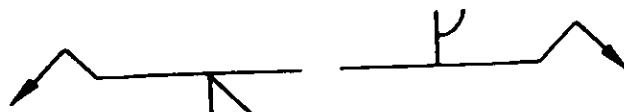
4.1.1 Single groove dimensions. Groove weld dimensions shall be specified on the same side of the reference line as the weld symbol [see Figure 11(A) and (F)].



4.1.2 Double-Groove Dimensions. Each groove of a double-groove joint shall be dimensioned; however, the root opening need appear only once (see Figure 12).



4.1.3 Broken Arrow. For bevel-groove and J-groove welds, a broken arrow is used, when necessary, to identify the member to be prepared (see 3.4).



4.2 Depth of Preparation and Groove Weld Size of Groove Welds

4.2.1 Location. The depth of groove preparation, S, and size (E) of a groove weld when specified, shall

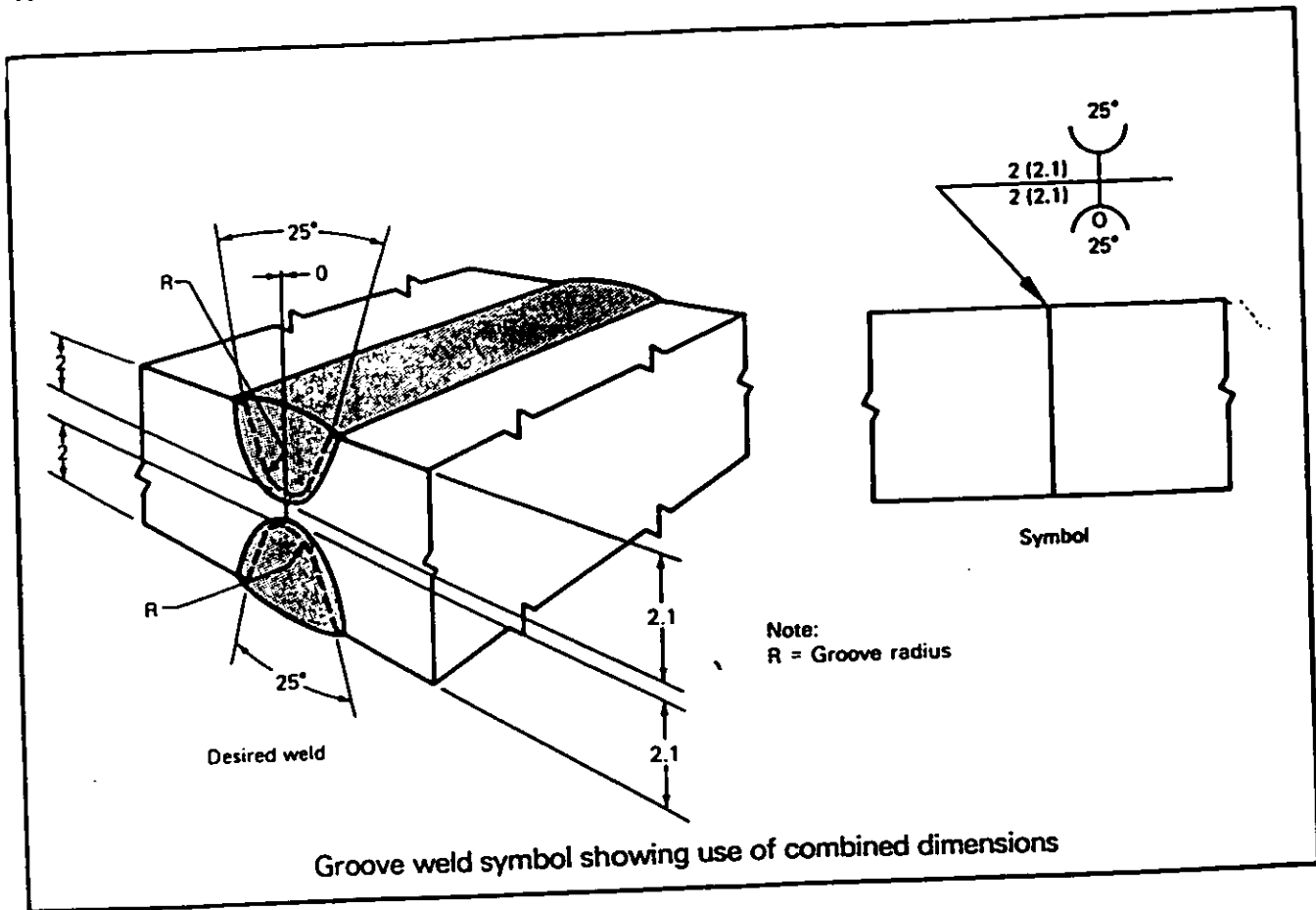
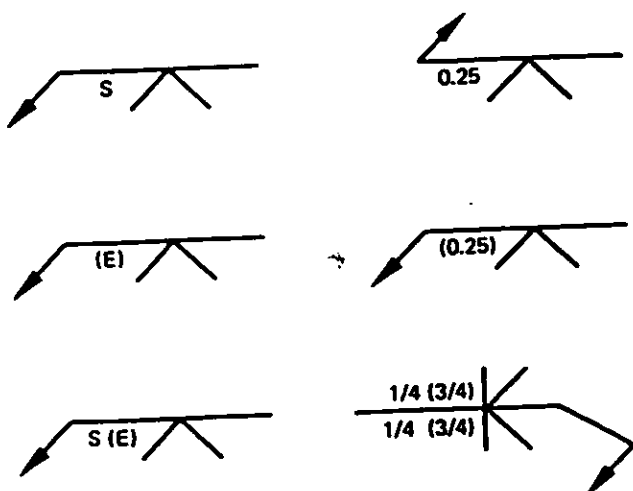
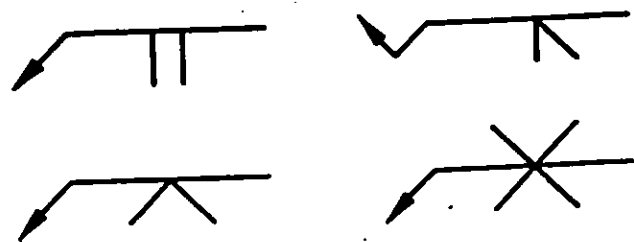


Figure 12 — Application of Dimensions to Groove Weld Symbols

be placed to the left of the weld symbol (see Figures 11-16).

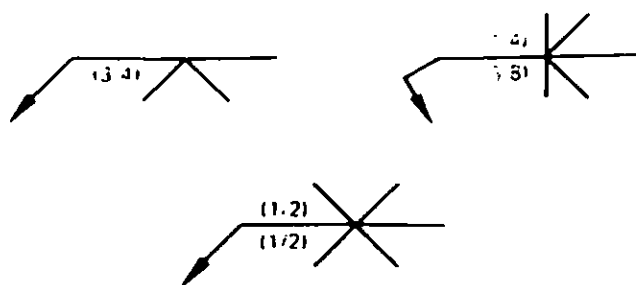


4.2.2 Complete Joint Penetration Required. When no depth of groove preparation and no groove weld size are specified on the welding symbol for single-groove and symmetrical double-groove welds, complete joint penetration is required [see Figure 11(D) and (E)].

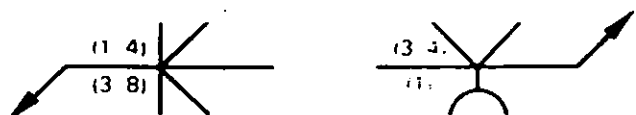


4.2.3 Joints with Partial Penetration, Size of Groove Weld Specified, Depth of Preparation Not Specified. The size of groove welds that extend only partly through

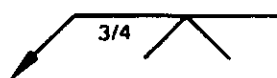
the joint shall be specified in parentheses on the welding symbol [see Figure 11(A), (C), and (E)].



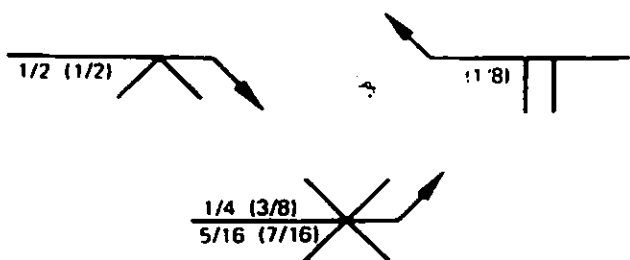
4.2.4 Welds with Complete Joint Penetration, Size of Groove Weld Specified, Depth of Preparation Not Specified. The size of nonsymmetrical groove welds that extend completely through the joint shall be specified in parentheses on the weld symbol (see Figure 15).



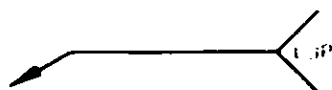
4.2.5 Depth of Preparation Specified, Size of Groove Weld Specified Elsewhere. A dimension not in parentheses placed to the left of bevel-, V-, J-, or U-groove weld symbol indicates only the depth of preparation.



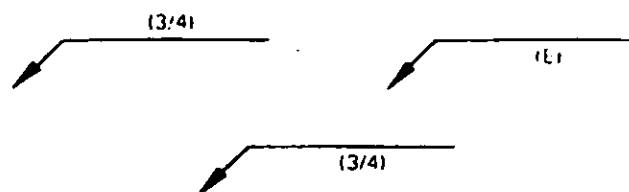
4.2.6 Depth of Preparation and Size of Groove Weld Specified. Except for square-groove welds, the groove weld size "E" in relation to the depth of groove preparation "S" is shown as "S(E)" to the left of the weld symbol. "E" only is shown for the square-groove weld (see Figures 13, 14, 16, and 19).



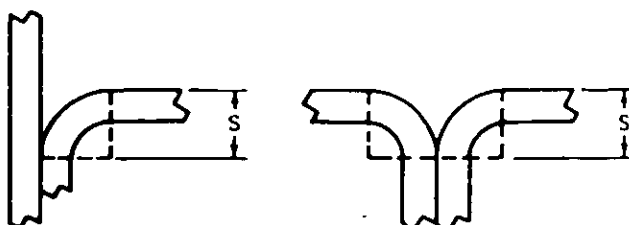
4.2.7 Joint Preparation Not Specified, Complete Joint Penetration Required. Optional joint preparation with complete joint penetration required is specified by placing the letters "CJP" in the tail of the arrow and omitting the weld symbol (see Figure 17).



4.2.8 Joint Penetration Not Specified, Size of Groove Weld Specified. For optional joint preparation, the groove weld size may be specified by placing the dimension "E" on the arrow side or other side of the reference line as required, but omitting the weld symbol (see Figure 18).



4.2.9 Flare-Groove Welds. The dimension "S" of flare groove welds is considered as extending only to the tangent point indicated below by dimension lines (see Figure 19).

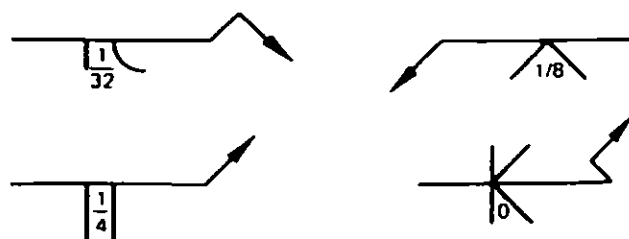


Flare-bevel-groove

Flare V-groove

4.3 Groove Dimensions

4.3.1 Root Opening. The root opening of groove welds shall be specified inside the weld symbol and only on one side of the reference line (see Figure 20).



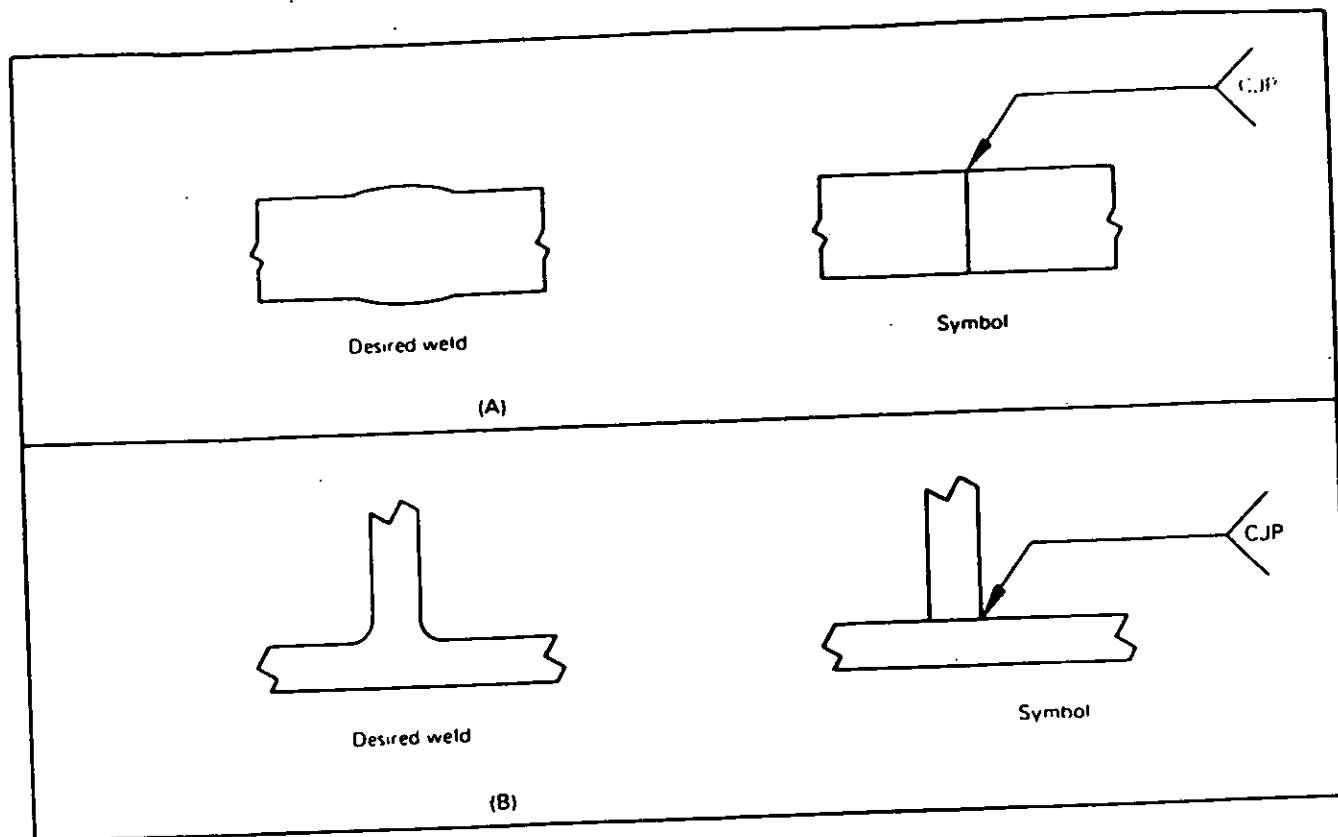
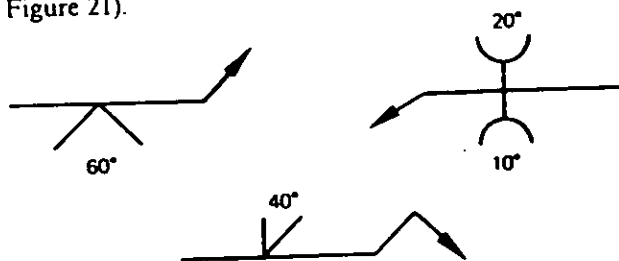
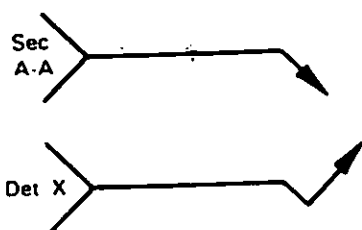


Figure 17 — Complete Joint Penetration Required, Joint Preparation Optional

4.3.2 Groove Angle. The groove angle of groove welds, shall be specified outside the weld symbol (see Figure 21).

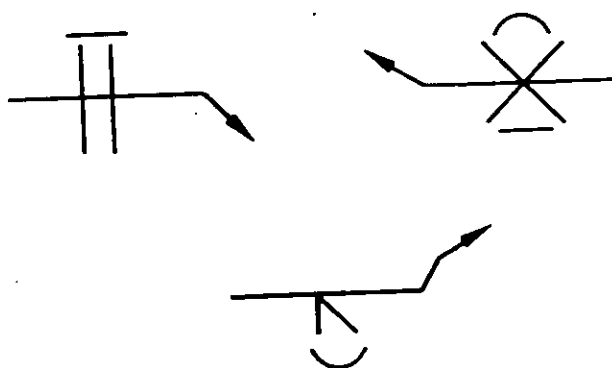


4.3.3 Radii and Root Faces. The groove radii and root faces of U- and J-groove welds shall be specified by a cross section, detail, or other data, with reference thereto in the tail of the welding symbol (see 3.10).



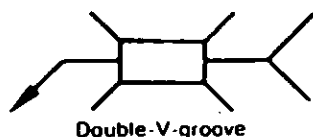
4.4 Contours and Finishing of Groove Welds

4.4.1 Contours Obtained by Welding. Groove welds that are to be welded with approximately flush or convex faces without postweld finishing shall be specified by adding the flush or convex contour symbol to the welding symbol (see Figure 22).

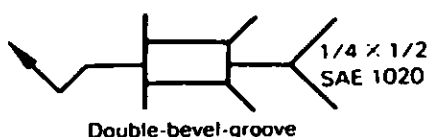


4.4.2 Contours Obtained by Postweld Finishing. Groove welds whose faces are to be finished flush or convex by postweld finishing shall be specified by adding both the appropriate contour and finishing symbol to the welding symbol. Welds that require a flat but not flush

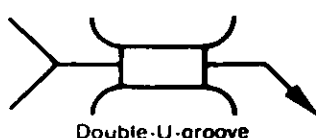
the rectangle need only appear on the reference line nearest to the arrow [see Figure 24(B) and (C)]. Material and dimensions of the spacer shall be specified in the tail of the symbol or on the drawing.



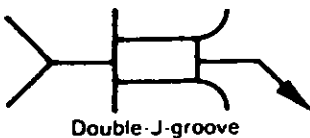
Double-V-groove



Double-bevel-groove

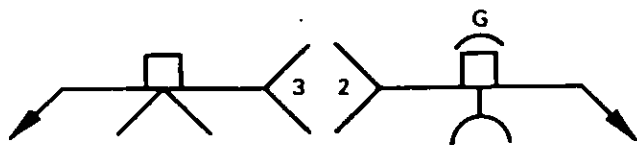


Double-U-groove



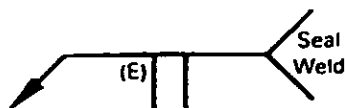
Double-J-groove

4.8 Consumable Inserts. Consumable inserts shall be specified by placing the consumable insert symbol on the side of the reference line opposite the groove weld symbol. The AWS consumable insert class shall be placed in the tail of the symbol (for insert class see latest edition of AWS A5.30).



4.9 Groove Welds with Back Gouging. A joint requiring complete penetration involving back gouging may be specified using either a single or multiple reference line symbol. That welding symbol shall include a reference to back gouging in its tail and (1) in the case of asymmetrical groove welds must show the depth of preparation from each side [see Figure 25(A) and (B)], together with groove angles and root opening, or (2) in the case of symmetrical groove welds, need not include any other information except the weld symbol [see 4.2.2 and Figure 25(C)], with groove angles and root opening.

4.10 Seal Welds. When the intent of the weld is to fulfill a sealing function only, the weld shall be specified in the tail of the symbol as a seal weld.

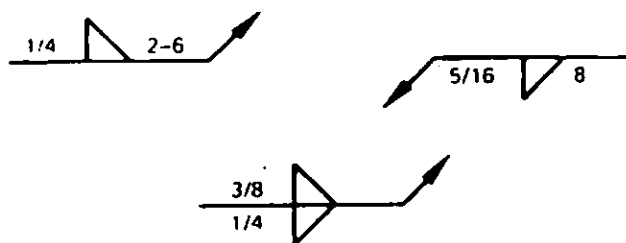


4.11 Skewed Joints. When the angle between the fusion faces is such that the identification of the weld type and hence, proper weld symbol is in question, the detail of the desired joint and weld configuration shall be shown on the drawing.

5. Fillet Welds

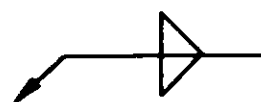
5.1 General

5.1.1 Dimension Location. Dimensions of fillet welds shall be shown on the same side of the reference line as the weld symbol (see Figures 26-28).



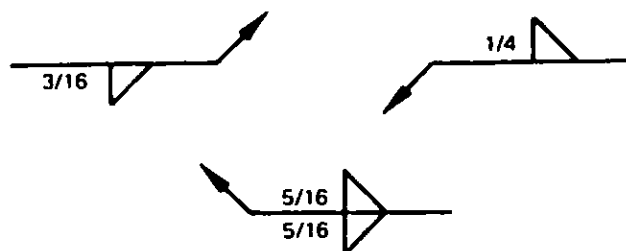
5.1.2 Double Fillet Welds. The dimensions of fillet welds on both sides of a joint shall be specified whether the dimensions are identical or different.

5.1.3 Drawing Notes. Dimensions of fillet welds covered by drawing notes need not be repeated on the welding symbols in accordance with 3.10.6.



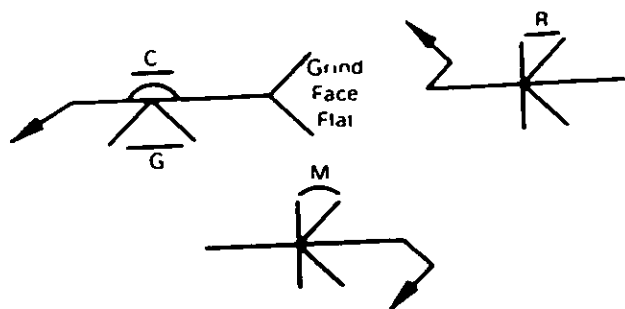
5.2 Size of Fillet Welds

5.2.1 Location. The fillet weld size shall be specified to the left of the weld symbol (see Figure 26).



5.2.2 Unequal Legs. The size of a fillet weld with unequal legs shall be specified to the left of the weld symbol as shown below. Weld orientation is not speci-

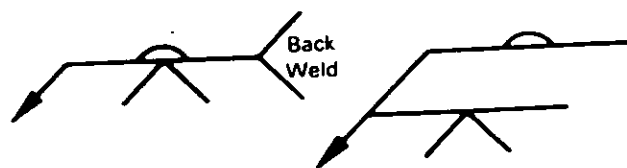
surface, require an explanatory note in the tail of the welding symbol (see 3.12.1).



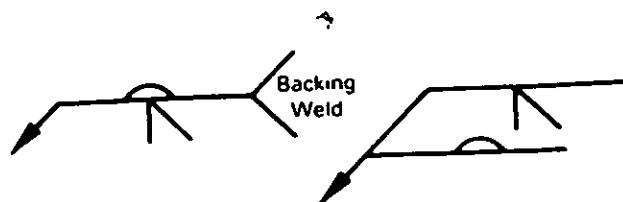
4.5 Back and Backing Welds

4.5.1 General. The back and backing weld symbols are identical. The sequence of welding determines which designation applies. The back weld is made after the groove weld and the backing weld is made before the groove weld (see 4.5.2 and 4.5.3).

4.5.2 Back Weld Symbol. The back weld symbol is placed on the side of the reference line opposite a groove weld symbol. When a single reference line is used, "back weld" shall be specified in the tail of the symbol. Alternatively, if a multiple reference line is used, the back weld symbol shall be placed on a reference line subsequent to the reference line specifying the groove weld [see Figure 23(A)].

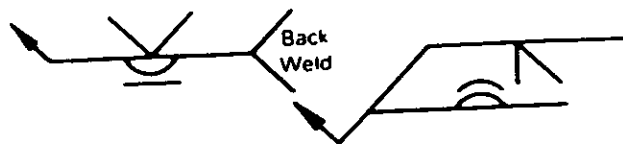


4.5.3 Backing Weld Symbol. The backing weld symbol is placed on the side of the reference line opposite a groove weld symbol. When a single reference line is used, "backing weld" shall be specified in the tail of the arrow. If a multiple reference line is used, the backing weld symbol shall be placed on a reference line prior to that specifying the groove weld [see Figure 23(B) and (C)].

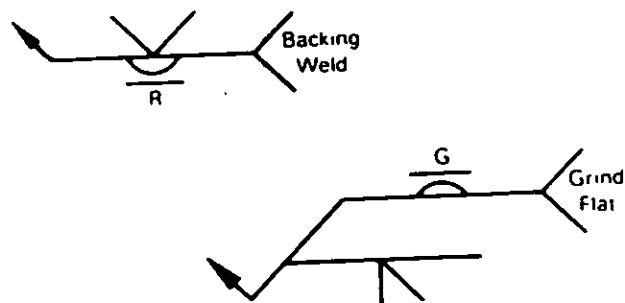


4.5.4 Contour and Finishing of Back or Backing Welds

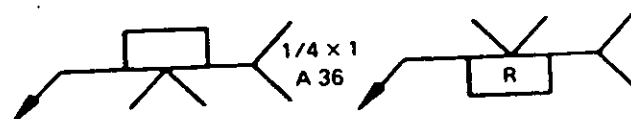
4.5.4.1 Contours Obtained by Welding. Back or backing welds that are to be welded with approximately flush or convex faces without postweld finishing shall be specified by adding the flush or convex contour symbol to the back or backing weld symbol (see 3.11).



4.5.4.2 Contours Obtained by Postweld Finishing. Back or backing welds that are to be finished approximately flush or convex by postweld finishing shall be specified by adding the appropriate contour and finishing symbols to the back or backing weld symbol (see 3.12.1). Welds that require a flat but not flush surface, require an explanatory note in the tail of the symbol.



4.6 Joint with Backing. A joint with backing is specified by placing the backing symbol on the side of the reference line opposite the groove weld symbol. If the backing is to be removed after welding, an "R" shall be placed in the backing symbol [see Figure 24(A)]. Material and dimensions of backing shall be specified in the tail of the symbol or on the drawing.



4.7 Joint with Spacer. A joint with a required spacer is specified with the groove weld symbol modified to show a rectangle within it. In case of multiple reference lines,

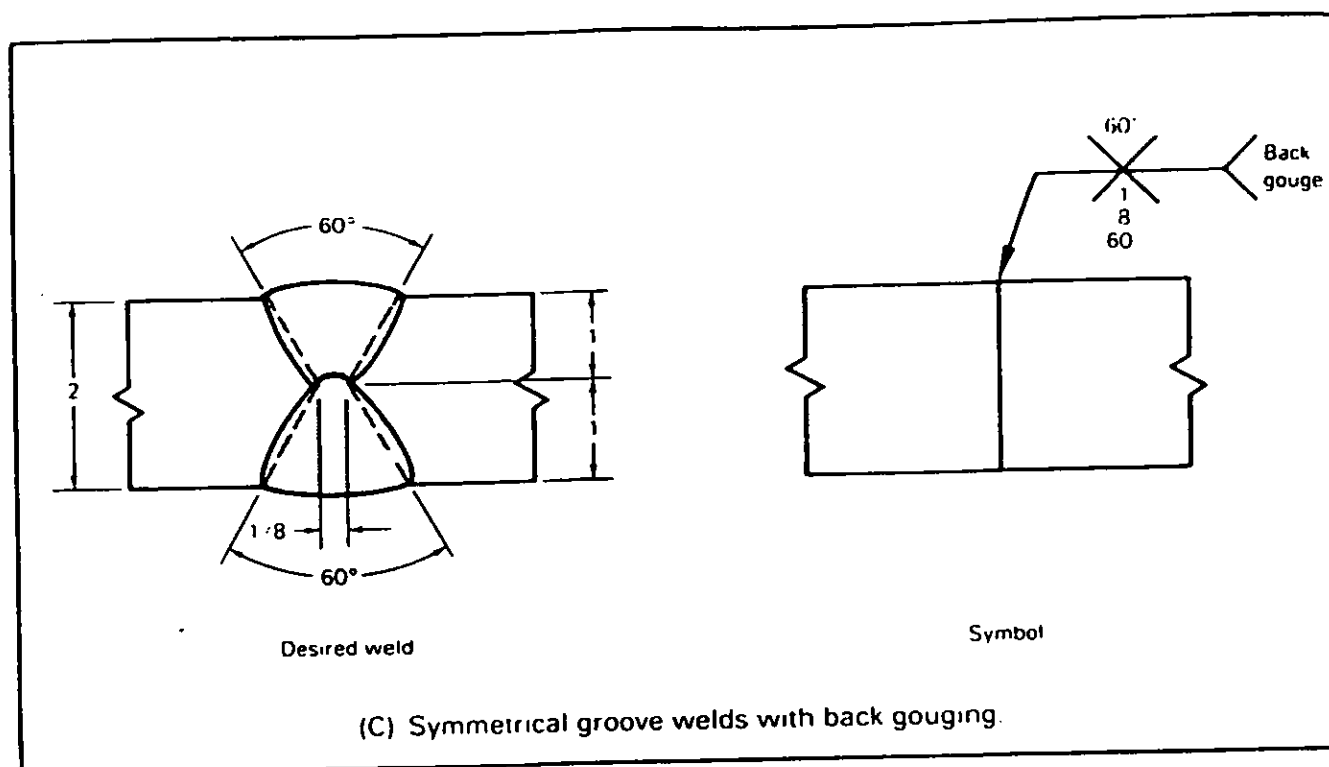
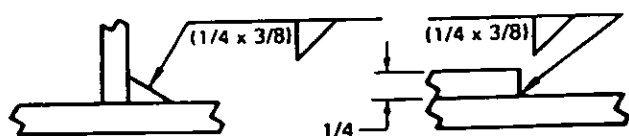


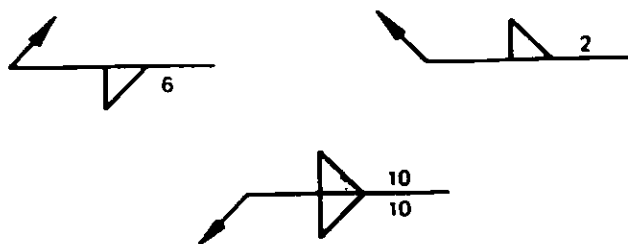
Figure 25 (continued) — Groove Welds with Back Gouging

fied by the symbol and shall be shown on the drawing to ensure clarity [see Figure 26(D)].



5.3 Length of Fillet Welds

5.3.1 Location. The length of a fillet weld, when indicated on the welding symbol, shall be specified to the right of the weld symbol [see Figure 26(F)].

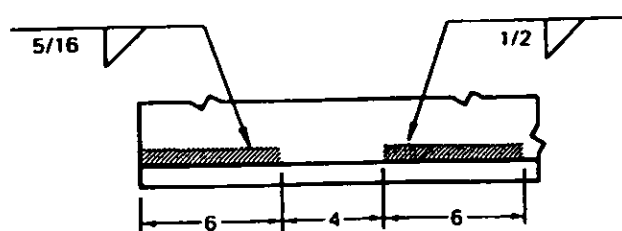


5.3.1.1 Full Length. When a fillet weld extends for the full length of the joint, no length dimension need be

specified on the welding symbol [see Figure 26(A), (B), (C), (D) and (E)].

5.3.1.2 Specific Lengths. Specific lengths of fillet welds, and their location, may be specified by symbols in conjunction with dimension lines [see Figures 8(C) and 26(F)].

5.3.1.3 Hatching. The extent of fillet welds may be specified graphically by hatching.



5.3.2 Changes in Direction of Welding. Symbols for fillet welds involving changes in the direction of welding shall be in accordance with 3.8.2 [see Figure 9(A)].

5.4 Intermittent Fillet Welds

5.4.1 Pitch. The pitch of intermittent fillet welds shall be the distance between centers of increments on one side of the joint (see Figure 27).

5.4.2 Pitch Dimension Location. The pitch of intermittent fillet welds shall be specified to the right of the length dimension following a hyphen (see Figure 27).



5.4.3 Chain Intermittent Fillet Welds. Dimensions of chain intermittent fillet welds shall be specified on both sides of the reference line. The segments of chain intermittent fillet welds shall be opposite one another across the joint [see Figure 27(B)].



5.4.4 Staggered Intermittent Fillet Welds. Dimensions of staggered intermittent fillet welds shall be specified on both sides of the reference line, and the fillet weld symbols shall not be directly opposite across the reference line. The segments of staggered intermittent fillet welds shall be symmetrically spaced on both sides of the joint as shown in Figure 27(C).



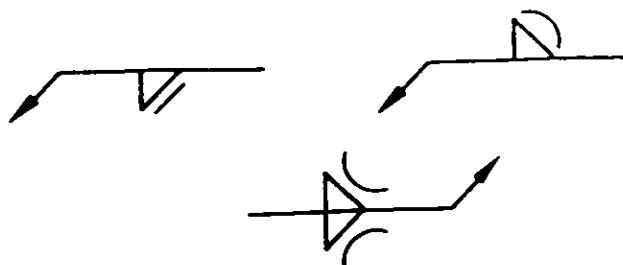
5.4.5 Extent of Welding. In the case of intermittent fillets, when additional welds are intended at the ends of the joint, they should be specified by separate symbols and dimensioned on the drawings. When no welds are intended at the ends of the joint, the unwelded length should not exceed that specified by the symbol and should be so dimensioned on the drawing.

5.5 Fillet Welds in Holes and Slots. Fillet welds in holes and slots shall be specified by the use of fillet weld symbols [see Figure 28(A)].

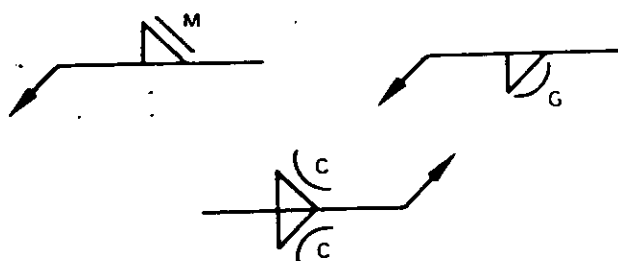
5.6 Contours and Finishing of Fillet Welds

5.6.1 Contours Obtained by Welding. Fillet welds that are to be welded with approximately flat, convex, or concave faces without postweld finishing shall be specified by adding the flat, convex, or concave contour

symbol to the weld symbol in accordance with the location conventions given in 3.1.



5.6.2 Contours Obtained by Postweld Finishing. Fillet welds whose faces are to be finished approximately flat, convex, or concave by postweld finishing shall be specified by adding both the appropriate contour and finishing symbol to the weld symbol (see 3.12.1).

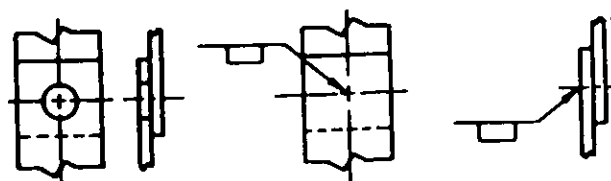


5.7 Skewed Joints. When the angle between the fusion faces is such that the identification of the weld type and, hence, proper weld symbol is in question, the detail of the desired joint and weld configuration shall be shown on the drawing.

6. Plug Welds

6.1 General

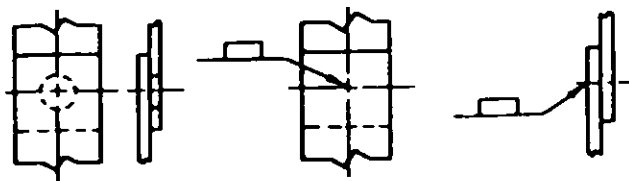
6.1.1 Arrow-Side Holes. Holes in the arrow-side member of a joint to be plug welded shall be specified by placing the weld symbol below the reference line [see Figure 29(A)].



Desired

Symbols

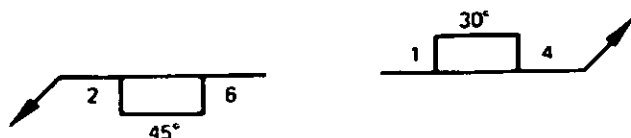
6.1.2 Other-Side Holes. Holes in the other-side member of a joint to be plug welded shall be specified by placing the weld symbol above the reference line [see Figure 29(B)].



Desired

Symbols

6.1.3 Dimensions. Dimensions of plug welds shall be specified on the same side of the reference line as the weld symbol (see Figure 30).

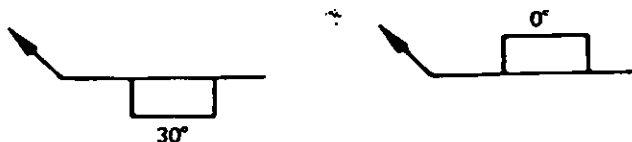


6.1.4 Fillets in Holes. The plug weld symbol shall not be used to designate fillet welds in holes (see 5.5).

6.2 Size of Plug Welds. The size of a plug weld shall be specified to the left of the weld symbol [see Figure 30(A), (B), (E), (F), and (G)]. Plug weld size is the diameter of the hole at the faying surface.



6.3 Angle of Countersink. The included angle of countersink of plug welds shall be specified either below or above the plug weld symbol [see Figure 30(B), (E), (F), and (G)].

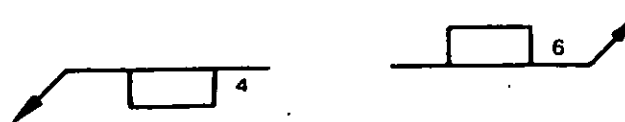


6.4 Depth of Filling. When the depth of filling is less than complete, it shall be specified inside the weld sym-

bol [see Figure 30(C) and (E)]. The omission of a depth dimension shall specify complete filling.



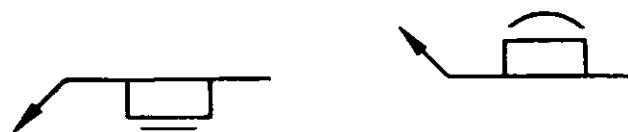
6.5 Spacing of Plug Welds. The pitch (center-to-center distance) of plug welds in a straight line shall be specified to the right of the weld symbol [see Figure 30(D) and (E)].



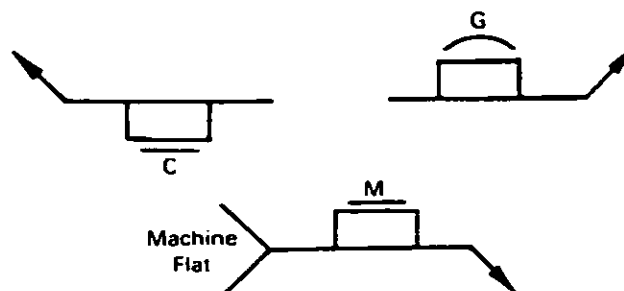
The spacing of plug welds in any configuration other than a straight line shall be dimensioned on the drawing.

6.6 Contours and Finishing of Plug Welds

6.6.1 Contours Obtained by Welding. Plug welds that are to be welded with approximately flush or convex faces without postweld finishing shall be specified by adding the flush or convex contour symbol to the weld symbol.



6.6.2 Contours Obtained by Postweld Finishing. Plug welds whose faces are to be finished approximately flush or convex by post weld finishing shall be specified by adding both the appropriate contour and finishing symbol to the welding symbol (see 3.12.1). Welds that require a flat but not flush surface, require an explanatory note in the tail of the symbol.



6.7 Joints Involving Three or More Members. Plug welding symbols may be used to specify welding two or

Table 1
Designation of Welding and Allied Processes by Letters

Welding and allied processes	Letter designation	Welding and allied processes	Letter designation
adhesive bonding	ABD	induction	RSEW-I
arc welding	AW	resistance spot welding	RSW
atomic hydrogen welding	AHW	upset welding	UW
bare metal arc welding	BMAW	high frequency	UW-HF
carbon arc welding	CAW	induction	UW-I
gas	CAW-G	soldering	S
shielded	CAW-S	dip soldering	DS
twin	CAW-T	furnace soldering	FS
electrode gas	EGW	induction soldering	IS
flux cored arc welding	FCAW	infrared soldering	IRS
gas metal arc welding	GMAW	iron soldering	INS
pulsed arc	GMAW-P	resistance soldering	RS
short circuiting arc	GMAW-S	torch soldering	TS
gas tungsten arc welding	GTAW	wave soldering	WS
pulsed arc	GTAW-P	solid-state welding	SSW
plasma arc welding	PAW	coextrusion welding	CEW
shielded metal arc welding	SMAW	cold welding	CW
stud arc welding	SW	diffusion welding	DFW
submerged arc welding	SAW	explosion welding	EXW
series	SAW-S	explosion welding	FW
brazing	B	forge welding	FRW
arc brazing	AB	friction welding	HPW
block brazing	BB	hot pressure welding	ROW
carbon arc brazing	CAB	roll welding	USW
diffusion brazing	DFB	ultrasonic welding	TC
dip brazing	DB	thermal cutting	AC
flow brazing	FLB	arc cutting	AAC
furnace brazing	FB	air carbon arc cutting	CAC
induction brazing	IB	carbon arc cutting	GMAC
infrared brazing	IRB	gas metal arc cutting	GTAC
resistance brazing	RB	gas tungsten arc cutting	MAC
torch brazing	TB	metal arc cutting	PAC
other welding processes		plasma arc cutting	SMAC
electron beam welding	EBW	shielded metal arc cutting	EBC
high vacuum	EBW-HV	electron beam cutting	LBC
medium vacuum	EBW-MV	laser beam cutting	LBC-A
nonvacuum	EBW-NV	air	LBC-EV
electroslag welding	ESW	evaporative	LBC-IG
flow welding	FLOW	inert gas	LBC-O
induction welding	IW	oxygen	OC
laser beam welding	LBW	oxygen cutting	FOC
thermit welding	TW	chemical flux cutting	POC
oxyfuel gas welding	OFW	metal powder cutting	OFC
air acetylene welding	AAW	oxyfuel gas cutting	OFC-A
oxyacetylene welding	OAW	oxyacetylene cutting	OFC-H
oxyhydrogen welding	OHW	oxyhydrogen cutting	OFC-N
pressure gas welding	PGW	oxynatural gas cutting	OFC-P
resistance welding	RW	oxypropane cutting	AOC
flash welding	FW	oxygen arc cutting	LOC
percussion welding	PEW	oxygen lance cutting	THSP
projection welding	PW	thermal spraying	ASP
resistance seam welding	RSEW	arc spraying	FLSP
high frequency	RSEW-HF	flame spraying	PSP
		plasma spraying	

NOTES

Arc welding safety can be divided into three areas:

1. protection against heat and light.
2. protection against electrical shock.
3. protection against fumes and gases.

Protection against heat and light

Welding gloves and other *leathers* should be worn to protect against exposure to heat and sparks. In addition, no part of the body should be exposed to the ultraviolet light emitted by the arc, otherwise a condition similar to severe sunburn could occur.

Particular attention should apply to the protection of the eyes by the use of a filter glass in accordance with BS 679 - *Specification for filters, cover lenses and backing lenses for use during welding and similar operations*.

Occasional *accidental* exposure to the eye can produce an extremely painful condition known as *arc eye* or *flash*, therefore the welding area should be screened to protect other personnel.

The light radiation will take the form of visible light, ultraviolet and infra red.

Protection against electrical shock

The voltage encountered with the majority of m.m.a. and t.i.g. welding plant is unlikely to exceed an o.c.v. of 100 V, however, the electric shock hazard at this level can be serious and a *low voltage safety device* should be incorporated into the circuit to protect the welder and other associated personnel. The lower voltage associated with m.i.g./m.a.g. is unlikely to present a problem. In all cases, the lower arc voltages (welding voltages) are regarded as quite safe.

To reduce the possibility of electrical shock, a correctly wired welding circuit should contain three leads:

- a *welding lead* from one terminal on the power supply unit to the electrode holder.
- a *welding return* from the other terminal on the power supply unit to the work.
- an *earth lead* from the work to an earth point.

All three leads should be of a size capable of carrying the highest welding current likely to be applied.

Protection against fumes and gases

Arc welding temperatures produce fume and dust particles which may be inhaled by the welder. The extent to which these particles constitute a health hazard depends upon their chemical composition. The maximum concentration to which a welder can be exposed to any one substance is specified as an *occupational exposure limit* as defined in the COSHH regulations 1988 and the supplementary document EH40.

Particular note should be made of the degreasing solvent trichlorethylene which, when exposed to either heat or ultraviolet arc radiation, will produce phosgene gas.

Fume may be removed at source by local extraction or by improving overall extraction in a fabrication shop or by providing the welder with a positive pressure welding helmet.

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Number	Title	
BS 427	Methods for Vickers hardness test.	
BS 499	Welding terms and symbols.	☒
BS 639	Specification for covered carbon and carbon manganese steel electrodes for manual metal-arc welding.	☒
BS 709	Methods of destructive testing fusion welded joints and weld metal in steel.	
BS 1113	Specification for design and manufacture of water-tube steam generating plant.	
BS 1295	Code of practice for training in arc welding skills. (Tests for use in training of welders).	
BS 1453	Specification for filler materials for gas welding.	
BS 1821	Specification for class I oxy-acetylene welding of ferritic steel pipework for carrying fluids.	
BS 2493	Specification for low alloy steel electrodes for manual metal-arc welding.	
BS 2633	Specification for class I arc welding of ferritic steel pipework for carrying fluids.	
BS 2640	Specification for class II oxy-acetylene welding of carbon steel pipework for carrying fluids.	
BS 2654	Specification for manufacture of vertical steel welded non-refrigerated storage tanks with butt welded shells for the petroleum industry.	
BS 2901	Filler rods and wires for gas-shielded arc welding.	☒
BS 2926	Specification for chromium and chromium nickel steel electrodes for manual metal-arc welding.	
BS 2971	Specification for class II arc welding of carbon steel pipework for carrying fluids.	
BS 3019	TIG welding.	
BS 3604	Steel pipes and tubes for pressure purposes: ferritic alloy steel with specified elevated temperature properties for pressure purposes.	
BS 3605	Specification for seamless tubes.	
BS 4165	Specification for electrode wires and fluxes for the submerged arc welding of carbon steel and medium-tensile steel	☒
BS 4360	Specification for weldable structural steels.	
BS 4515	Specification for welding of steel pipelines on land and offshore.	
BS 4570	Specification for fusion welding of steel castings.	
BS 4677	Specification for arc welding of austenitic stainless steel pipework for carrying fluids.	
BS 4872	Specification for approval testing of welders when welding procedure approval is not required.	
BS 5135	Specification for arc welding of carbon and carbon manganese steels.	☒
BS 5289	Code of practice. Visual inspection of fusion welded joints.	☒
BS 5465	Specification for electrodes and fluxes for the submerged arc welding of austenitic stainless steels.	
BS 5500	Specification for unfired fusion welded pressure vessels.	
BS 6323	Specification for seamless and welded steel tubes for automobile, mechanical and general engineering purposes.	

NOTES

Number	Title	
BS 6693	Method for determination of diffusible hydrogen in weld metal.	
BS 6990	Code of practice for welding on steel pipes containing process fluids or their residuals.	
BS 7084	Specification for carbon and carbon-manganese steel tubular cored welding electrodes.	
BS 7191	Specification for weldable structural steels for fixed offshore structures.	
BS 7418	Code of practice for isolation of the welding circuit in arc welding plant.	
BS 7570	Code of practice for validation of arc welding equipment.	
PD 6493	Guidance on methods for assessing the acceptability of flaws in fusion welded structures.	
BS EN 287	Approval testing of welders for fusion welding.	☒
BS EN 288	Specification and approval of welding procedures for metallic materials.	☒
BS EN 10002	Tensile testing of metallic materials.	
BS EN 10020	Definition and classification of grades of steel.	
BS EN 10027	Designation systems for steel.	
BS EN 10045	Charpy impact tests on metallic materials.	
BS EN 10204	Metallic products-Types of inspection documents.	
BS EN 24063	Welding, brazing, soldering and braze welding of metals. Nomenclature of processes and reference numbers for symbolic representation on drawings.	
BS EN 25817	Arc welded joints in steel. Guidance on quality levels for imperfections.	☒
BS EN 26520	Classification of imperfections in metallic fusion welds, with explanations.	☒
BS EN 26848	Specification for tungsten electrodes for inert gas shielded arc welding and for plasma cutting and welding.	
AWS A5.1	Specification for covered carbon steel arc welding electrodes.	☒
AWS A5.17	Specification for carbon steel electrodes and fluxes for submerged arc welding.	
AWS A5.4	Specification for covered corrosion-resisting chromium and chromium-nickel steel welding electrodes.	
AWS A5.5	Specification for low alloy steel covered arc welding electrodes.	☒
AWS B1.0	Guide for the non-destructive testing of welds.	
AWS B2.1	Standard welding procedure specifications.	
AWS B4.0	Methods for mechanical testing of welds.	
AWS D1.2	Structural welding code (aluminium).	
AWS D10.9	Specification for qualification of welding procedures and welders for piping and tubing.	

NOTES

The CSWIP SWI examination will require the assessment of two fracture specimens. The report must show/state the following:

- a. any welding defects present;
- b. the fracture initiation point(s) and their characteristics;
- c. the main or primary mode of failure, e.g. fatigue;
- d. any secondary mode of failure, e.g. brittle fracture;
- e. whether the failure occurred in weld metal, parent metal or both.

Fractures in steels may propagate in one or more modes, dependant upon various factors which may include:

- a. type of stress - tensile, shear, impact, cyclic, combination;
- b. speed of loading - high speed, medium speed, slow speed, very slow speed;
- c. temperature - high temperature, room temperature, low temperature;
- d. environment - air, corrosive, protected, e.g. oil.

The fracture mode itself may be either (1) ductile; (2) brittle; (3) fatigue; (4) combination.

Ductile fractures

Ductile fractures always show plastic deformation usually at 45° angle to the load. the surface will exhibit a rough, fibrous appearance. In low carbon steels under test, e.g. tensile or bend, *necking* of the specimen will occur. Failure will usually be associated with the formation of *shear lips*.

In tensile failures, the fracture surface may also show small dimples and peaks (cups and cones), these are caused by inclusions and voids.

A shear load would cause a fibrous fracture surface with well defined shear lips:

Compressive stress applied to a ductile steel will produce considerable metal spread and edge cracking:

Note: Ductile fractures which occur under dynamic loading (impact) have a dull grey appearance with extensive plastic deformation (shear lips) which would increase with the toughness of the material.

NOTES

Brittle fractures

Brittle fractures occur with little or no plastic deformation. In general, high levels of stress and low temperature promote brittle fractures which may travel at very high speed at 90° to the load causing the formation of *vees* or *chevrons* which point backwards towards the point of initiation.

Brittle fractures which occur under dynamic loading, e.g. impact have a bright, shiny faceted or crystalline surface.

Fatigue fractures

A fatigue fracture is basically a *brittle* fracture but always develops from a flaw, e.g. arc strike, undercut, inclusion etc. by small step propagation at 90° to the load with an increasing acyclic (arc) appearance on an otherwise smooth surface producing the effect known as *beach marking*.

NOTES

Combination modes

Fracture surfaces may exhibit one or more of the previously described modes of failure, e.g. fatigue, followed by either brittle or ductile failure. This is representative of a static (gradually) applied load as in a CTOD test or may show both ductile and brittle fracture modes as produced by dynamic (impact) loading as achieved for example in a charpy test.

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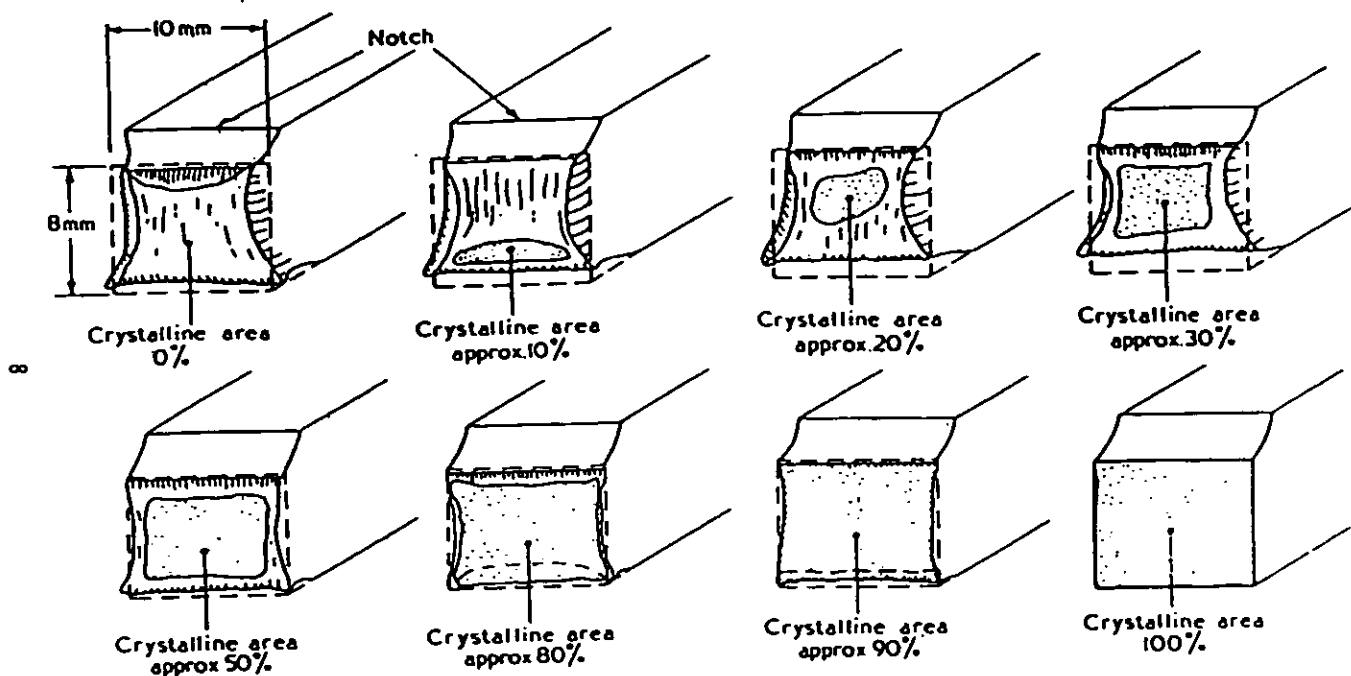


Fig. 1. Typical examples of guide diagrams

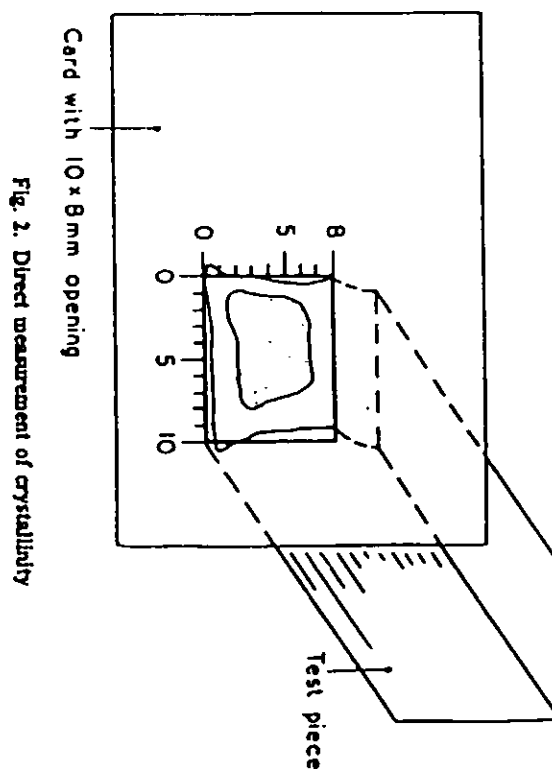


Fig. 2. Direct measurement of crystallinity

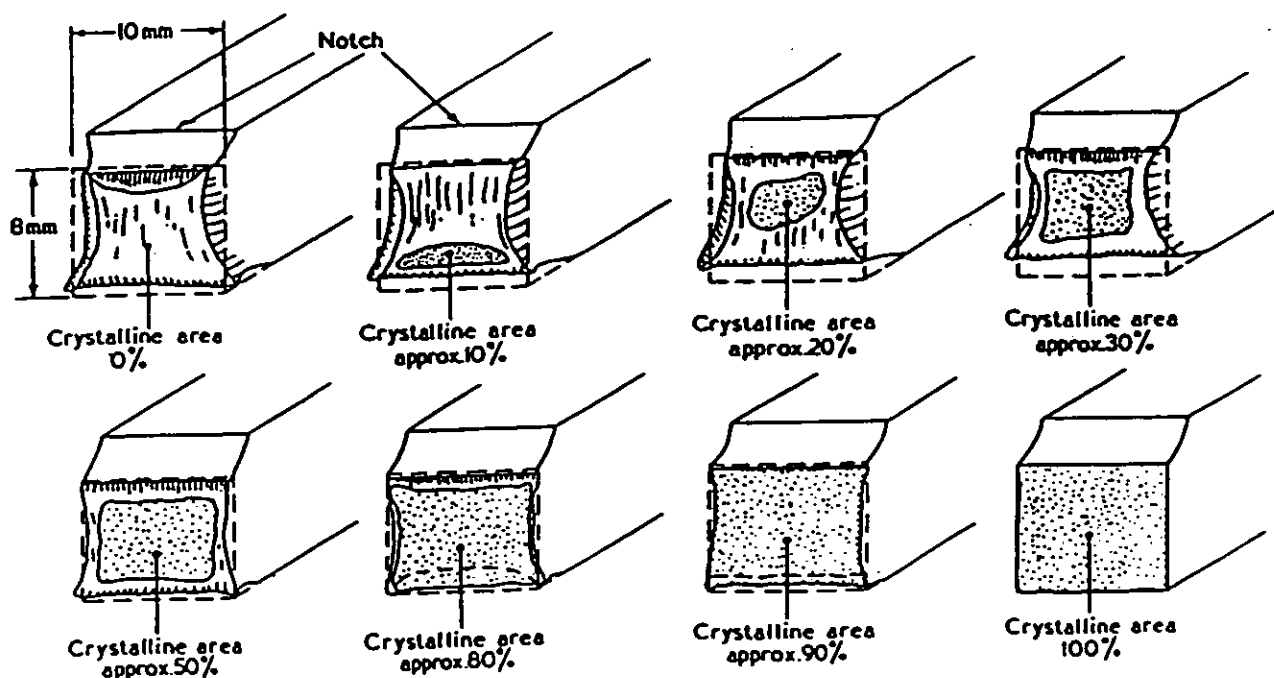


Fig. 1. Typical examples of guide diagrams

BRITISH STANDARD METHODS FOR NOTCHED BAR TESTS

Part 5. Determination of Crystallinity

FOREWORD

This British Standard has been prepared as part of the second revision of B.S. 131, Parts 1, 2 and 3 of the standard, dealing respectively with the Izod, Charpy V- and Charpy U- notch impact tests on metals, and Part 4, covering the calibration of pendulum impact testing machines have already been published.

The increasing use of percentage crystallinity as one of the criteria for assessing the notch ductility of steel by means of notched bar tests has prompted the issue of this standard, which assumes that a broken Izod or Charpy test piece, having a cross-section of 10 mm x 8 mm below the notch, is to be examined. The methods for estimating the percentage of crystalline fracture are, however, generally applicable to any area of fractured surface. When fracture does not occur by cleavage, brittle areas may occur as the result of inter-crystalline fracture or 'flat' fracturing. In such cases the distinction between the crystalline and fibrous areas may be less well defined, and expert interpretation may be required.

For notched bars other than stated in Clause 1, the methods of determination described in this standard may also be applied provided that the same definition (see Clause 2) is used and suitable reference diagrams or control test pieces are available.

It is emphasized that, for the purposes of this standard, the definition of crystalline fracture is general and refers to that part of the fracture surface which has a bright sparkling appearance.

The standard is not concerned with the interpretation or significance of crystallinity, which depends on the type of test, the material considered and the application.

METHODS

SCOPE

1. This British Standard describes methods for determining the percentage of crystallinity in the fractures of notched bar test pieces of carbon, carbon-manganese and low-alloy steel, with particular reference to test pieces of the forms specified in B.S. 131*, Parts 1, 2 and 3.

* B.S. 131, 'Methods for notched bar tests', Part 1, 'The Izod impact test on metals', Part 2, 'Charpy V-notch impact test', Part 3, 'Charpy U-notch impact test'.

TERMINOLOGY

2. When a notched bar test piece of a metal is broken by bending, the individual crystals may fracture either by cleavage or by shear, and both modes may occur in the same fracture.

In cleavage, the crystals fracture on crystallographic planes, which appear as bright sparkling facets, giving the appearance known as 'crystalline'.

In the shear mode, the crystals elongate and deform, producing a silky texture described as 'fibrous'.

The 'percentage of crystallinity' is defined as the total area of the crystalline portions of the fractured test piece expressed as a percentage of the original cross-sectional area of the test piece below the notch.

Example. For a Charpy test piece in which the cross-sectional area below the notch is 8 mm x 10 mm, i.e. 80 mm², if the total area of crystallinity were 32 mm², the percentage of crystallinity would be $\frac{32}{80} \times 100 = 40$ per cent.

RECOGNITION OF CRYSTALLINITY

3. The crystalline portions of the fractured surface can be distinguished visually by their bright, sparkling appearance, particularly when viewed from several angles under a point source of light, or by parallel light. An ordinary light bulb is preferable to strip lighting, and a small, brilliant bulb in a parabolic reflector gives the best practical contrast. The fibrous areas are characterized by a relatively dull or silky appearance.

DETERMINATION OF CRYSTALLINITY

4. The percentage crystallinity shall, in general, be estimated by one of the following methods, but other methods agreed between the interested parties are not precluded.

a. Direct visual estimation. In this method, the fracture of one half of the broken test piece is examined (see Clause 3) and the percentage crystallinity is estimated either by comparison with guide diagrams of the type shown in Fig. 1, or by reference to a set of control test pieces for which the percentages of crystallinity have been determined more accurately.

b. Direct measurement. In this method, the crystalline areas are measured, without magnification, by means of a scale marked in millimetres, or preferably using a card having an opening graduated in millimetres, as indicated in Fig. 2.

c. Measurement with magnification. In this method, the fracture surface is viewed under low optical magnification (say x 10) preferably by means of an optical projector or projection microscope. The crystalline area is traced on a piece of paper and the area estimated, for example, by one of the following procedures:

- (i) by counting squares, if squared paper or a transparent graticule is used;
- (ii) by means of a planimeter;
- (iii) by weighing the paper representing the crystalline area on a suitable balance.

Alternatively, the crystalline area is determined by the use of a graticule in the eye piece of an ordinary, monocular or binocular low-powered microscope.

NOTE. When there are several crystalline areas, the aggregate area is to be used in calculating the percentage. Small isolated cleavage facets may be ignored.

ACCURACY

5. For most purposes, an accuracy to ± 10 per cent crystallinity is adequate, and this can usually be achieved by an experienced operator using the method described in Subclause 4a.

When more accurate determinations are required, methods such as those described in Subclauses 4b and c should be used.

It is desirable that when methods a or b are used occasional checks should be made by method c.

PRESENTATION OF RESULTS

6. The results of determinations made in accordance with this standard shall be reported as 'percentage crystalline' as defined by the following formula:

$$\text{Percentage crystallinity} = \frac{\text{Crystalline area}}{\text{Original cross-sectional area below the notch}} \times 100$$

The values obtained may be rounded to the nearest 5 per cent unless a specially high degree of accuracy is required and is warranted by the method of determination used.

The method of determination (see Clause 4) shall be indicated.

If, for any reason, it is required to report the results of determinations in terms of 'percentage fibrous', such results shall only be derived by subtracting the crystalline area from the original cross-sectional area, i.e.

$$100 \left(1 - \frac{\text{Crystalline area}}{\text{Original cross-sectional area below the notch}} \right) \text{ per cent}$$

TERMINOLOGY

2. When a notched bar test piece of a metal is broken by bending, the individual crystals may fracture either by cleavage or by shear, and both modes may occur in the same fracture.

In cleavage, the crystals fracture on crystallographic planes, which appear as bright sparkling facets, giving the appearance known as 'crystalline'.

In the shear mode, the crystals elongate and deform, producing a silky texture described as 'fibrous'.

The 'percentage of crystallinity' is defined as the total area of the crystalline portions of the fractured test piece expressed as a percentage of the original cross-sectional area of the test piece below the notch.

Example. For a Charpy test piece in which the cross-sectional area below the notch is $8 \text{ mm} \times 10 \text{ mm}$, i.e. 80 mm^2 , if the total area of crystallinity were 32 mm^2 , the percentage of crystallinity would be $\frac{32}{80} \times 100 = 40$ per cent.

RECOGNITION OF CRYSTALLINITY

3. The crystalline portions of the fractured surface can be distinguished visually by their bright, sparkling appearance, particularly when viewed from several angles under a point source of light, or by parallel light. An ordinary light bulb is preferable to strip lighting, and a small, brilliant bulb in a parabolic reflector gives the best practical contrast. The fibrous areas are characterized by a relatively dull or silky appearance.

DETERMINATION OF CRYSTALLINITY

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a. Direct visual estimation. In this method, the fracture of one half of the broken test piece is examined (see Clause 3) and the percentage crystallinity is estimated either by comparison with guide diagrams of the type shown in Fig. 1, or by reference to a set of control test pieces for which the percentages of crystallinity have been determined more accurately.

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- (ii) by means of a planimeter;
- (iii) by weighing the paper representing the crystalline area on a suitable balance.

Alternatively, the crystalline area is determined by the use of a graticule in the eye piece of an ordinary monocular or binocular low-powered microscope.

NOTE. When there are several crystalline areas, the aggregate area is to be used in calculating the percentage. Small isolated cleavage facets may be ignored.

ACCURACY

5. For most purposes, an accuracy to ± 10 per cent crystallinity is adequate, and this can usually be achieved by an experienced operator using the method described in Subclause 4a.

When more accurate determinations are required, methods such as those described in Subclauses 4b and c should be used.

It is desirable that when methods a or b are used occasional checks should be made by method c.

PRESENTATION OF RESULTS

6. The results of determinations made in accordance with this standard shall be reported as 'percentage crystalline' as defined by the following formula:

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The values obtained may be rounded to the nearest 5 per cent unless a specially high degree of accuracy is required and is warranted by the method of determination used.

The method of determination (see Clause 4) shall be indicated.

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$$100 \left(1 - \frac{\text{Crystalline area}}{\text{Original cross-sectional area below the notch}} \right) \text{ per cent}$$

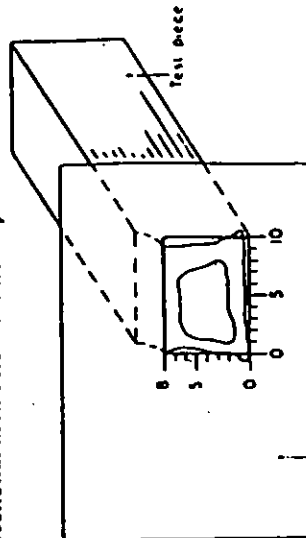


Fig. 2. Direct measurement of crystallinity

**QUALITY ASSURANCE,
AN APPRECIATION**

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NOTES

Aim of quality assurance

The aim of quality assurance is to improve quality whilst keeping costs to an acceptable level.

The objective of a system used to implement quality assurance, i.e. a *quality system*, is to prevent the occurrence of problems which result in remedial action. If problems do occur the objective is to determine and rectify the root cause(s), thereby reducing faults and wastage in the future. This will in turn, improve quality and reduce costs.

The emphasis is on prevention rather than detection and cure.

Benefits of adopting quality assurance

A properly implemented and managed quality system should:

- a. help to ensure that the company focuses on market needs and requirements.
- b. make the company more competitive in the market place due to an increased customer confidence in the company's output, i.e. a product or service that a customer wants - this includes timing.
- c. lead to a reduction of costs due to a reduced number of faults and wastage.
- d. give a measure of performance which will enable any areas for improvement to be identified.
- e. induce a more organized way of thinking which makes management more organized and effective.
- f. provide motivation; motivated employees provide a better working environment in addition to the product or service output benefits.

What is quality assurance?

The definition for *quality assurance* given in ISO 8402 : 1986 (BS 4778 : Part 1) entitled *Quality vocabulary*:

'All those planned or systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.'

The quality of a product or service is attained only by working in a controlled manner, following formalised procedures which are designed to eliminate the occurrence of problems.

Quality assurance provides the objective evidence needed to give maximum confidence for quality.

Quality assurance may be considered as a management tool when used within an organization. A supplier that implements and maintains a system for assuring quality, is providing maximum confidence to a purchaser, or potential purchaser, that the supplied product or service attains, or is going to attain, its fitness for purpose.

Different people have different concepts for what is meant by a *quality* product or service, therefore it is very important to be aware of the customers' requirements and/or expectations.

Contract documents or purchasing specifications should clearly define a company's requirements for a product or service. The quality of the product or service is deemed to have been achieved when the exact requirements have been met completely and consistently - assuming correct specification!

NOTES

Scope of quality assurance

Quality assurance should encompass all parts of an organization and all phases of an activity, i.e. planning, design, production, maintenance, administrative etc. in order to give a purchaser, or potential purchaser, maximum confidence that the client's expectations for quality have been met. Collaboration with suppliers and purchasers should also be part of an organization's quality system.

QA, QC and inspection compared

Quality assurance is not inspection. Inspection is one of the important elements within a system for quality assurance. Inspection requires continuing evaluation in the same way as the other elements, e.g. planning, design/specifications, production etc...

Inspection is defined in BS 4778 : Part 1 as: 'activities such as measuring, examining, testing, gauging one or more characteristics of a product or service and comparing these with specified requirements to determine conformity.'

Inspection is also defined in EN 45020 : 1993 : *Glossary of terms for standardization and related activities*: 'Evaluation for conformity by measuring, observing, testing or gauging the relevant characteristics.' *Evaluation for conformity* is defined in the same standard as: 'Systematic examination of the extent to which a product, process or service fulfils specified requirements.'

Quality control is defined in BS 4778 : Part 1 as: 'the operational techniques and activities that are used to fulfil requirements for quality.' This definition can be vague, so modifying the term to be more specific is advantageous, e.g. *manufacturing quality control*.

Quality control is involved with the monitoring of a process and eliminating the causes of any deficient output of a process, or any phase during a contract, which has an effect on quality. The information obtained from inspection, as defined above, is used for quality control.

Quality control deals with the actual measurement of quality performance which is compared against what is required and action is taken on the difference. Quality control is asking the question, "is the work/action being performed correctly"?

Quality control does not reach all elements which affect quality, e.g. quality control will rarely do anything to correct problems relating to management, traceability, training and staff motivation.

Quality assurance applies to all areas which have an affect on quality, and asks the question, "has the work/action been performed correctly"? This question can only be asked after information has been obtained from quality control and all other departments/areas which affect quality.

QA standards

BS EN ISO 9000 series - *Quality systems*.

BS 4778 - *Quality vocabulary*.

[EN 28402; ISO 8402]

BS EN 30011 - *Guidelines for auditing quality systems*.

NOTES

1. **Normative document:** Document that provides rules, guidelines or characteristics for activities or their results.

Note: The term *normative document* is a generic term that covers such documents as *standards, technical specifications, codes of practice and regulations*.
[ISO Guide 2 & EN 45020]

2. **Standard:** Document, established by *consensus* and approved by a recognized *body*, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context.
[ISO Guide 2 & EN 45020]

3. **Code of practice:** Document that recommends practices or procedures for the design, manufacture, installation, maintenance or utilization of equipment, structures or products.
Note: A *code of practice* may be a *standard* a part of a *standard* or independent of a *standard*.
[ISO Guide 2 & EN 45020]

4. **Specification:** The document that prescribes the *requirements* with which the product or service has to conform.
Note: A *specification* should refer to or include drawings, patterns or other relevant documents and should also indicate the means and the criteria whereby *conformity* can be checked.
[BS 4778 : Part 1]

5. **Technical specification:** Document that prescribes technical *requirements* to be fulfilled by a product, process or service.
Note: A *technical specification* should indicate, wherever appropriate, the procedure(s) by means of which it may be determined whether the requirements given are fulfilled.
A *technical specification* may be a *standard* a part of a *standard* or independent of a *standard*.
[ISO Guide 2 & EN 45020]

6. **Regulation:** Document providing binding legislative rules, that is adopted by an *authority*.
Note: An *authority* is a body that has legal powers and rights.
[ISO Guide 2 & EN 45020]

7. **Procedure (1):** Specified way to perform an activity.
[ISO 8402 & ISO 10005]

8. **Procedure (2):** A written description of all essential parameters and precautions to be observed when applying inspection or a test method to a specific item or quantity of items, following an established standard, code or specification.
[ICORR REQ 96]

9. **Instruction:** *Provision* that conveys an action to be performed.
[ISO Guide 2 & EN 45020]

10. **Written instruction:** A detailed written description of the inspection(s) or test(s) to be performed.
[ICORR REQ 96]

NOTES

Introduction

What is quality assurance? Common perceptions include: fitness for purpose, the requirement to get it right first time every time, good management, etc.. Many *one liners* are used to try and explain the meaning and relevance of quality assurance and although many of these are useful in describing certain aspects of quality assurance, they are not comprehensive enough or meaningful, to leave the layman with an understanding of the subject.

The subject of quality assurance needs much greater analysis to understand fully its meaning, aims and implications.

Quality assurance is a subject area which is often misunderstood and misused in industry, mainly due to a lack of awareness and understanding through a lack of formal training.

Aim of quality assurance

The aim of quality assurance is to improve quality whilst keeping costs to an acceptable level.

The objective of a system used to implement quality assurance, i.e. a *quality system*, is to prevent the occurrence of problems which result in remedial action. If problems do occur the objective is to determine and rectify the root cause(s), thereby reducing faults and wastage in the future. This will in turn, improve quality and reduce costs.

The emphasis is on prevention rather than detection and cure.

Benefits of adopting quality assurance

The benefits of quality assurance are now widely accepted in industry, however, there are sceptics who assume a quality assurance system to be a massive financial burden with nothing to show for it except a mountain of quality related paperwork or information on computer disks which they cannot cope with! There are other sceptics who accept that a better quality product or service is achieved, but again, at a greatly increased financial cost to the company.

If a mountain of paperwork has evolved it is likely that most of it is irrelevant, and the relevant information could be collated more efficiently. The inauguration of a quality system always costs money but if properly implemented the system should create a monetary return.

A properly implemented and managed quality system should:

- a. help to ensure that the company focuses on market needs and requirements.
- b. make the company more competitive in the market place due to an increased customer confidence in the company's output, i.e. a product or service that a customer wants - this includes timing.
- c. lead to a reduction of costs due to a reduced number of faults and wastage.
- d. give a measure of performance which will enable any areas for improvement to be identified.
- e. induce a more organized way of thinking which makes management more organized and effective.
- f. provide motivation; motivated employees provide a better working environment in addition to the product or service output benefits.

NOTES

Contract phases

In order to understand the applicability of quality assurance, it is necessary to understand the phases involved for a contract. The following text implies that the contract is relative to the manufacture of a product, or products, which are to be designed, made, installed and put into service. However, the information presented may easily be adjusted for contracts with less phases, and for service type contracts.

List of contract phases:

1. Bid enquiry and tender (including some planning at this stage).
2. Contract acceptance.
3. Planning.
4. Design/specification.
5. Procurement (purchasing).
6. Production (manufacture/fabrication).
7. Final inspection and testing.
8. Packaging, storage and shipping.
9. Installation and operation/commission (where applicable).
10. Handover to customer.
11. Technical assistance and maintenance.
12. Warranty (where applicable).
13. Disposal after use.

NOTES

What is quality assurance?

The definition for *quality assurance* given in ISO 8402 : 1986 (BS 4778 : Part 1) entitled *Quality vocabulary*:

'All those planned or systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.'

Other definitions or description of quality assurance encountered may include:

- a. A management system designed to ensure, or at least give maximum confidence that a product or service attains its fitness for purpose at minimum (acceptable) cost, i.e. the product or service attains its intended attributes, but no more and no less.
- b. Integrated management systems that provide an assurance that the contractual and legal obligations to the customer and the community are fulfilled.
- c. Good management.
- d. Formalised common sense!

The quality of a product or service is attained only by working in a controlled manner, following formalised procedures which are designed to eliminate the occurrence of problems.

Quality assurance provides the objective evidence needed to give maximum confidence for quality.

Quality assurance may be considered as a management tool when used within an organization. A supplier that implements and maintains a system for assuring quality, is providing maximum confidence to a purchaser, or potential purchaser, that the supplied product or service attains, or is going to attain, its fitness for purpose.

Different people have different concepts for what is meant by a *quality* product or service, therefore it is very important to be aware of the customers' requirements and/or expectations.

Two main purchaser-supplier relationships exist: (1) those using a formal written contract and (2) those which do not. In both situations, it is essential at the order stage, that the contracting parties understand and agree the specific requirements for the product or service to be supplied.

Contract documents or purchasing specifications should clearly define a company's requirements for a product or service. The quality of the product or service is deemed to have been achieved when the exact requirements have been met completely and consistently - assuming correct specification!

Scope of quality assurance

Quality assurance should encompass all parts of an organization and all phases of an activity, i.e. planning, design, production, maintenance, administrative etc. in order to give a purchaser, or potential purchaser, maximum confidence that the client's expectations for quality have been met. Collaboration with suppliers and purchasers should also be part of an organization's quality system. See also the quality system elements listed in Unit QA4.

It is interesting to note that the National/International Standards which give models for quality systems, do not encompass quality related costs or product safety and reliability. However, this does not mean to say that quality costs, safety and reliability are not considered in relation to quality. These areas and others not identified in National/International Standards may, and should, still be part of an organizations quality system.

NOTES

The significance approach to quality

The significance approach to quality assurance analyses and attempts to identify the degree of control required to assure the quality of a product, service or process.

Too much control would produce unnecessary cost, too little may produce a reduction or loss in quality, e.g. defective output.

The degree of significance is governed by:

- a. The requirements you are obliged to comply with, i.e. by law (statutory), by other regulations (regulatory), or by contract.
- b. The degree of necessity to be right first time, i.e. there may not be the possibility to maintain or rectify faults.
- c. The consequence of failure: personnel safety; plant safety; commercial implications; environmental impact.
- d. The probability of failure based on: quality history, or lack of it; the complexity of the product, service or process; any external influences.

QA, QC and inspection compared

Quality assurance is not inspection. Inspection is one of the important elements within a system for quality assurance. Inspection requires continuing evaluation in the same way as the other elements, e.g. planning, design/specifications, production etc...

Inspection is defined in BS 4778: Part 1 as: activities such as measuring, examining, testing, gauging one or more characteristics of a product, service and comparing these with specified requirements to determine conformity.

Inspection is also defined in BS 4778: Part 1 as: *any of the terms for standardization, and related activities. Evaluation for conformity by measuring, observing, testing or gauging the relevant characteristics.* Evaluation for conformity is defined in the same standard as: *Systematic examination of the extent to which a product, process or service fulfils specified requirements.*

Quality control is defined in BS 4778: Part 1 as: the operational techniques and activities that are used to fulfil requirements for quality. This definition can be vague, so modifying the term to be more specific is advantageous, e.g. manufacturing quality control.

Quality control is involved with the monitoring of a process and eliminating the causes of any deficient output of a process, or any phase during a contract, which has an effect on quality. The information obtained from inspection, as defined above, is used for quality control.

Comparison between quality control and quality assurance is more difficult to explain because of different beliefs between experts. Assumptions are also made regarding the applicability of the term *quality control*, e.g. is it referring to manufacturing quality control or company-wide quality control?

Quality control deals with the actual measurement of quality performance which is compared against what is required and action is taken on the difference. Quality control is asking the question, "is the work/action being performed correctly?"

Quality control does not reach all elements which affect quality, e.g. quality control will rarely do anything to correct problems relating to management, traceability, training and staff motivation.

Quality assurance applies to all areas which have an effect on quality, and asks the question, "has the work/action been performed correctly?" This question can only be asked after information has been obtained from quality control and all other departments/areas which affect quality.

NOTES

Quality management is defined in BS 4778 : Part 1 as: 'That aspect of the overall management function that determines and implements the quality policy.'

Quality assurance requires managing like other functions within an organization, such as production, purchasing or inspection. Management of quality still involves planning, the allocation of resources and evaluation.

Each element in a quality system requires management through documentation and formalised structure.

It is not the intent of National/International Quality Standards to tell managers how to manage or run their business. The intent of these Standards is to show which elements need formalised management to attain quality.

The responsibility for the implementation and management of quality assurance within an organization must be held by senior management. Certain responsibilities may be delegated, but senior management must be ultimately responsible for quality assurance to be effective. It is important to note however that all members of an organization must have a commitment to quality and must participate accordingly.

The output/information obtained from having a quality management system includes:

- a. A written quality policy.
- b. A description of the company organization.
- c. The allocation of responsibilities for the main functions which have an affect on quality.
- d. Standards to be attained within the company.
- e. Management procedures for conducting business and the attainment of quality.
- f. Decisions regarding quality and quality assurance.

Quality policy

Quality policy is defined in BS 4778 : Part 1 as: 'The overall quality intentions and direction of an organization as regards quality, as formally expressed by top management.'

The company policy on quality within an organization must be decided before a quality system is documented or managed. Quality systems may vary widely between different organizations because of different quality objectives, different scopes of work and different methods of working.

NOTES

Quality system is defined in BS-4778: Part I as, 'the organizational structure, responsibilities, procedures, processes and resources for implementing quality management.'

An organization's quality system is part of its total management system, but does not exist as a separate entity. A quality system is integrated into most, if not all, of the management systems - similar to your nervous system.

A quality system within an organization is implemented by the use of written procedures which cover all those aspects which govern the final quality of a product or a service. The *quality manual* is a document in which the quality system is referred to as a whole. Reference is made in the quality manual to the relevant procedures to be used to implement the system.

The quality system needs to be comprehensive enough to meet the quality objectives of the organization. It is no good making a quality system so comprehensive and complicated that it becomes impossible to manage and adhere to; this is just as bad as having an oversimplified or incomplete system.

Quality systems and associated documentation should ideally be:

- a. Simple.
- b. Logical.
- c. Clear.
- d. Complete.
- e. Concise.
- f. Correct.
- g. User friendly.

A quality system should produce records reflecting the true situation regarding quality. The records will include audit results, minutes from reviews and any other analysis or feedback with regard to the operation of the system. It is for management to assess these records and act on them accordingly.

Quality system elements

A quality system should encompass all those areas which have an affect on quality. These areas may be referred to as the *quality system elements*.

When any of these elements are present in a quality system standard, there is a requirement for formality in their management.

Examples of quality system elements:

- a. Management responsibility.
- b. Quality system principles.
- c. Auditing the quality system - internal.
- d. Economics - Quality-related cost considerations.
- e. Quality in marketing (Contract review).
- f. Quality in specification and design (Design control).
- g. Quality in procurement (Purchasing).
- h. Quality in production (Process control).
- i. Control of production.
- j. Material control and traceability (Product identification and traceability).
- k. Control of verification status (Inspection and test status).
- l. Product verification (Inspection and testing).
- m. Control of measuring and test equipment (Inspection, measuring and test equipment).
- n. Nonconformity (Control of nonconforming product).
- o. Corrective action.
- p. Handling and post-production functions (Handling, storage, packaging, preservation and delivery).
- q. After-sales servicing.
- r. Quality documentation and records (Control of quality records).

NOTES

- s. Personnel (Training).
- t. Product safety and liability.
- u. Use of statistical methods (Statistical techniques).
- v. Purchaser supplied product.

Note: The titles in parentheses are taken from clauses/sub-clauses in ISO 9001.

Measurement and calibration system

Overview

How does a supplier or a purchaser have maximum confidence that a product meets the specified requirements in terms of its physical attributes, e.g. correct dimensions, correct mass, correct light intensity etc.?

Confidence is gained by using a calibration system to attempt to ensure that all measuring equipment is accurate to within stated tolerances.

A calibration system is necessary for a supplier to be assured of the correct measurements of its own products. A calibration system is also necessary for purchaser that wishes to verify conformance of the supplied product (assuming the purchaser is not using a third party for verification).

Calibration system

A calibration system should ensure that all measuring equipment has the capability of making measurements within defined tolerances. These tolerances must be appropriate to the measuring equipment, e.g. it is not realistic to specify a 0.01 mm tolerance over the length of a 1 m steel rule.

A calibration system should attempt to prevent inaccuracies occurring, or at least ensure that any deficiency in measuring equipment is detected before use.

A calibration system should allow time for any detected deficiencies to be corrected.

A calibration system should be reviewed periodically and systematically.

Traceability

In most circumstances, measurement standards and measuring equipment used should, where possible, be traceable back to national or international standards. The calibration system should provide the objective evidence that this is ultimately the case.

This does not mean to say that all measurement standards, e.g. weights for calibrating balances, ultrasonic calibration blocks, density strips etc. need to be sent to an accredited calibration laboratory every three months or whatever. Providing the traceability requirement is satisfied, intermediate standards which may not have been directly referenced to national/international measurement standards may still be used.

Frequency of calibration

Where practical, all measuring equipment and calibration standards should be identified to indicate their calibration status, e.g. by the use of labels or tags. Where it is not practical to identify equipment in this way, the calibration procedure should identify how the equipment is controlled to meet the specified requirements.

The frequency of checking and calibration depends on various factors:

- a. Type of measuring equipment.
- b. Amount and degree of use.
- c. Purpose of measurement.
- d. Stability of measuring equipment.

NOTES

Calibration records

Calibration records should include the following information:

- a. The description of equipment and unique identification.
- b. The date on which each calibration was performed.
- c. The results obtained from calibration.
- d. The planned calibration interval and, where appropriate, the following additional information:
 - e. The designated permissible limits of error.
 - f. The reference to calibration procedures.
 - g. The source of calibration used to establish traceability.
 - h. The environmental condition for calibration and the measurement data as measured and as corrected to reference conditions.
 - i. A statement of the cumulative effect of uncertainties on the data obtained in the calibration.
 - j. Details of any maintenance (servicing, adjustment, repairs) or modifications that could affect the calibration status.
 - k. Any limitations in use.

Quality plans

Quality plan is defined in BS 4778 : Part 1 as, 'A document setting out the specific quality practices, resources and sequence of activities relevant to a particular product, service, contract or project.'

A quality plan is a supplementary quality system document.

The purpose of a quality plan is essentially the same as that for an organizations quality system except that it relates to a new product, service or process, e.g. a specific contract or purchase order.

Quality plans may encompass entire projects - project quality plans, or be more specific to functions or phases within a project, e.g. quality control plans.

For example, a quality plan may be proposed, agreed and used, for: the radiographic examination of weldments on certain pressure vessels, for painting inspection on a particular oil rig, or for the erection of specific aerial towers etc..

Quality manuals and procedures

Quality manual is defined in BS 4778 : Part 2 as, 'A document setting out the general policies, procedures, and practices of an organization.'

The *quality manual* is the next stage after senior management have taken the decision to implement a quality system and agreed a quality policy.

There is no universally accepted way for writing a quality manual or installing a quality system because quality assurance standards do not stipulate how documentation should be rationalized; the following text offers some guidance to promote structured thinking.

The following sequence of operations may be used:

1. Document the existing organizational structure and responsibilities of key personnel.
2. Document the existing procedures from the receipt of orders through to handover to the customer or beyond if necessary.
3. Analyse the existing system, compare with the requirements and document any proposed amendments.
4. Decide on the number of quality document tiers necessary to achieve objectives.

NOTES

It is often preferable for a suitable representative from the organisation who is closely involved with a specific activity to produce the lower tier procedures and/or work instructions, or at least produce draft versions, e.g. how to use a particular machine; how to calibrate a particular test instrument; how to mix ingredients etc..

5. Propose your structure and any changes to existing practices to the organization - management.
6. When structure and changes are agreed, produce draft quality documents (quality manual and at least 1st tier procedures).
7. Produce final quality documents when final drafts are agreed.

If you are the person who is to document the quality system and you are external to the organization, you will need to be accompanied when at the premises, virtually the whole time, by the person within the organization who will be responsible for the quality system.

Make use of the *four task elements* as you document the existing structure and work procedures. Think about the system from an auditor's point of view. Look closely at interfaces.

Follow logical routes when questioning, for example:

1. How does the company receive an order - letter? telex? telefax? verbal?
2. Who may receive orders?
3. Who is responsible for orders/processing orders?
4. How is the order processed?
5. How is the order recorded/filed?
6. Is it possible for orders to go astray?
7. Have orders ever gone astray?

Make note of any system deficiencies without detracting too far from the job in hand. Try to resist making immediate major changes to existing systems - even if considered necessary. Gradual systematic change is desirable to allow for human aspects.

When the quality system is implemented, the quality manual and quality related procedures, instructions, drawings etc. need to be controlled and amended when necessary. All changes to the system or any quality document should be recorded.

NOTES

A *quality audit* is defined in *BS 4778: Part 1* as, 'a systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives.'

This definition is all encompassing and can relate to audits applied to entire quality systems, parts of a quality systems, to products or services, or to processes.

Audits may be carried out by:

- a. a company on its own systems - known as an *internal* or *first party* audits.
- b. an organisation on a supplier or potential supplier - known as *external* or *second party* audits.
- c. accreditation authorities on an organisation who is accredited, or wishes to be accredited, to the authorities quality standard - known as *extrinsic* or *third party* audits.

The purpose of an audit on a quality system is to obtain objective evidence of the practices and results of quality related activities, to then compare these findings against the documented planned arrangements, in order to provide an assurance that those planned arrangements are complied with.

The objective evidence may be quantitative or qualitative, but must be based on fact, i.e. measurement, test or observation; not subjective opinion. The documented planned arrangements are those in the quality manual and related procedures.

An audit is typically conducted in five phases:

1. The opening meeting.
2. The audit.
3. Evaluation of audit findings.
4. The closing meeting.
5. The submission of an audit report including any *corrective action requests* on *non-conformities* found.

A follow up audit, which should be treated as a separate audit, may be required if any corrective action is to be undertaken based on the original audit results.

Prior to an audit it is necessary to draw up a checklist and/or sequence of questions covering all applicable areas of the audit. The checklist should be produced with reference to the associated documentation, e.g. the quality manual, procedures and any applicable standard.

The *BS EN 30011 - Guidelines for auditing quality systems* is a document which may be referred to for more information on the auditing of quality systems.

NOTES

Quality: The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs. (BS 4778 : Part 1)

Quality assurance: All those planned or systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality. (BS 4778 : Part 1) - *Setting up, Has it been done?*

Quality control: The operational techniques and activities that are used to fulfil requirements for quality. (BS 4778 : Part 1) - *Is it been done?*

Quality management: That aspect of the overall management function that determines and implements the quality policy. (BS 4778 : Part 1)

Quality manual: A document stating the quality policy, quality system and quality practices of an organization. (BS 4778 : Part 2)

Quality plan: A document setting out the specific quality practices, resources and sequence of activities relevant to a particular product, service, contract or project. (BS 4778 : Part 1)

Quality policy: The overall quality intentions and direction of an organization as regards quality, as formally expressed by top management. (BS 4778 : Part 1)

Quality system: The organizational structure, responsibilities, procedures, processes and resources for implementing quality management. (BS 4778 : Part 1)

NOTES

	BS 4778 : Part 1 [EN 28402, ISO 8402]	Quality vocabulary - International terms.
10	BS 4778: Part 2	Quality vocabulary - Quality concepts and related definitions.
	BS EN ISO 9000-1	Quality management and quality assurance standards Part 1: Guidelines for selection and use.
20	BS EN ISO 9000-2	Quality management and quality assurance standards. Part 2: Generic guidelines for the application of ISO 9001, ISO 9002 and ISO 9003.
	BS EN ISO 9001	Quality systems - Model for quality assurance in design, development, production, installation and servicing.
30	BS EN ISO 9002	Quality systems - Model for quality assurance in production, installation and servicing.
	BS EN ISO 9002	Quality systems - Model for quality assurance in final inspection and check.
40	ISO 9004-1	Quality management and quality assurance standards. Part 1: Guidelines.
	ISO 9004-2	Quality management and quality assurance standards. Part 2: Guidelines for services.
50	ISO 10005	Quality management - Guidelines for quality plans.
	BS EN 30011	Guide for auditing quality systems (Parts 1, 2 and 3).

NOTES

1. **Normative document:** Document that provides rules, guidelines or characteristics for activities or their results.
Note: The term *normative document* is a generic term that covers such documents as *standards, technical specifications, codes of practice and regulations*.
[ISO Guide 2 & EN 45020]
2. **Standard:** Document, established by *consensus* and approved by a recognized *body*, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context.
[ISO Guide 2 & EN 45020]
3. **Code of practice:** Document that recommends practices or procedures for the design, manufacture, installation, maintenance or utilization of equipment, structures or products.
Note: A *code of practice* may be a *standard* a part of a *standard* or independent of a *standard*.
[ISO Guide 2 & EN 45020]
4. **Specification:** The document that prescribes the *requirements* with which the product or service has to conform.
Note: A *specification* should refer to or include drawings, patterns or other relevant documents and should also indicate the means and the criteria whereby *conformity* can be checked.
[BS 4778 : Part 1]
5. **Technical specification:** Document that prescribes technical *requirements* to be fulfilled by a product, process or service.
Note: A *technical specification* should indicate, wherever appropriate, the procedure(s) by means of which it may be determined whether the requirements given are fulfilled.
A *technical specification* may be a *standard* a part of a *standard* or independent of a *standard*.
[ISO Guide 2 & EN 45020]
6. **Regulation:** Document providing binding legislative rules, that is adopted by an *authority*.
Note: An *authority* is a body that has legal powers and rights.
[ISO Guide 2 & EN 45020]
7. **Procedure (1):** Specified way to perform an activity.
[ISO 8402 & ISO 10005]
8. **Procedure (2):** A written description of all essential parameters and precautions to be observed when applying inspection or a test method to a specific item or quantity of items, following an established standard, code or specification.
[ICORR REQ DOC]
9. **Instruction:** *Provision* that conveys an action to be performed.
[ISO Guide 2 & EN 45020]
10. **Written instruction:** A detailed written description of the inspection(s) or test(s) to be performed.
[ICORR REQ DOC]

QUALITY ASSURANCE - QUESTION PAPER

PAPER No. Q-QA1

TIME ALLOWED - 2 HOURS

1. Explain what you understand by the following terms:
 - a. Specification.
 - b. Standard.
 - c. Code of practice.
 - d. Test procedure.
2. What is your definition of *quality assurance*?
3. What is a *quality plan*?
4. List the headings you would expect to find on a test procedure. Include only those which are likely to be common to all test procedures.
5. What is the purpose of a quality system audit on a sub-contractor who is already on the company's list of approved suppliers?
6. What is the purpose of a *certificate of conformance*?
7. What is a *certificate of compliance*?
8. What is a *non-conformity*?
9. Define the difference(s) between *quality control* and *quality assurance*.
10. How thorough is it necessary to make an organization's Quality Manual?

QUALITY ASSURANCE - QUESTION PAPER

PAPER No. Q-QA2

TIME ALLOWED - 3 HOURS

1. 100 welds attaching pipe to pipe were inspected by MPI by a team of three operatives from an inspection company. All welds were reported as being defect free.

The client reinspected the welds and found that 30% of the inspected welds contained defects which exceeded the acceptance tolerance.

Identify which quality aspects which may have been neglected in this situation.

2. A failure has occurred on a weld connecting a small bore set-on attachment fitting to a pipe. The failure initiated from the outer surface at the weld toe. NDT was not originally specified as a requirement. Any future failures could have significant safety and economic consequences.

You are responsible for quality on a related project with similar welds and have been asked to review your quality procedures to prevent future problems in similar circumstances. What questions will you be asking in order to make your review?

3. Because of previous oversights during quality reviews, you have been requested by your manager to produce an all encompassing checklist for use in management meetings which review overall quality.

Because your company has a quality system which meets the requirements of BS 5750 : Part 1 you have decided to refer to this document for guidance. Draw up your proposed checklist. *Open book question - BS 5750 : Part 1.*

AUDITING

The four task elements

INFORMATION	PERSON	ITEM	EQUIPMENT
Documentation/ computer disks - identified - approved - type - content - distribution - records Verbal Memory	Identified Qualified - trained - experienced - certified Attributes Wellbeing Accountability Responsibility Availability Motivated	Identified Type Condition Environment Status	Identified Type Condition Environment Available Status Capacity

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1 Information

- 1.1 Were the inspections carried out in accordance with an approved written procedure?
- 1.2 If a written procedure was used, did all concerned have a copy?
- 1.3 If a written procedure was used, did it allow for different techniques or test sensitivities to be adopted?
- 1.4 If a written procedure was used, did the MPI operatives (including client's inspector) work to the same procedure, e.g. same issue; same test sensitivity?
- 1.5 What was the NDT procedure and technique employed technically correct, i.e. could the procedure specified lead to misleading indications?
- 1.6 If a written procedure was used, were the results reported in accordance with the requirements of that procedure?
- 1.7 Did the procedure precisely specify which areas required testing on each weld or did it allow for random inspection, i.e. could the client's inspector have tested the welds in a different area to the MPI operatives?

2 Person

- 2.1 Were the defective checks attributable to one NDT technician or to all of them.
- 2.2 Was there any supervision - to whom did the operatives report.
- 2.3 Was each NDT operative in possession of the NDT procedure.
- 2.4 Were all the NDT operators qualified to use the procedure.
- 2.5 Had the NDT operator's vision been checked.
- 2.6 Could the NDT operative(s) responsible for the tests have been unwell or under the influence of drink or drugs.
- 2.7 Were the NDT operatives experienced in the use of the specific procedure to test the actual weld configuration.
- 2.8 Were the NDT operatives aware of which defects they could expect to detect.
- 2.9 Were the NDT operatives permanent full-time employees or contracted in.
- 2.10 Were the NDT checks the only work done on the days in question or did the operatives have other duties.
- 2.11 Were there any time pressures involved during the first inspection.
- 2.12 What evidence is there that the initial inspections were actually performed.
- 2.13 Any reason to doubt the integrity of any of the operatives.

3 Equipment

- 3.1 What equipment was used to carry out the tests.
- 3.2 What calibrations or checks were carried out on the magnets used.
- 3.3 What consumables were used in the initial inspections - what was the shelf-life status. Were any checks made on the suspension or particles.
- 3.4 Was the same combination of magnets/consumables used in all tests.
- 3.5 Is the equipment used for the initial tests traceable and available for evaluation.
- 3.6 If the inspections were performed inside the pipe, what was the system used and did all the equipment, torches etc. function.

4 Item

- 4.1 Was there any significant event between the two inspections, e.g. stress applied to welds, grinding, hydrostatic testing, post-weld heat treatment.
- 4.2 Were the 30% of welds sequential or randomly distributed in the string.
- 4.3 Did the defect occur in the same position relative to the circumference.
- 4.4 Was the defect the same type in all welds.
- 4.5 Was the surface condition identical for both sets of inspections.
- 4.6 If the inspections were carried out inside the pipe, were the correct safety procedures observed.
- 4.7 Were both inspections performed under identical environmental conditions.
- 4.8 Were the inspections carried out inside the pipe or outside the pipe.
- 4.9 Could there have been any confusion as to which welds were checked.

5 Miscellaneous

- 5.1 Have the welds been re-checked by a third party.
- 5.2 At what time of day did the inspections take place—what were the viewing conditions, what were the weather conditions.
- 5.3 When did the initial check take place—how soon after welding.

QUALITY ASSURANCE - QUESTION PAPER

PAPER No. Q-QA3

TIME ALLOWED - 2 HOURS

1. What are the objectives of quality assurance?
2. Why are quality audits carried out?
3. List the *four task elements* with a description of the applicability of each term.
4. From a customer's point of view, when is *quality* deemed to have been achieved?
5. Give five examples of quality system elements as described in BS 5750.
6. What is the meaning and relevance of the abbreviation *CAR*?
7. What is the purpose of a *quality policy*?
8. What is the purpose of issuing an instrument with a *certificate of calibration*?
9. What is the BS 4778?
10. What do you understand by the *significance approach to quality*?

QUALITY ASSURANCE - QUESTION PAPER EAU9

PAPER No. Q-QA4

TIME ALLOWED - 2 HOURS

1. List five items of information you would expect to find in calibration records.
2. What do you understand by *quality document tiers*?
3. What is a *document transmittal sheet*?
4. What is a *third party audit*?
5. List four phases of an audit after the opening meeting.
6. What is the difference between *procurement price* and *purchase price*?
7. Why is there a potential problem with *on the job training*?
8. What is meant by a *controlled document*?
9. List the benefits and potential benefits for a company with a properly implemented quality system.
10. What is the purpose of a *hold area*?

NOTES

On ferromagnetic materials it is normally preferable to use m.p.i.

Penetrant testing

This type of testing uses the forces of capillary action to detect surface breaking defects. It is impossible to detect defects which do not break the surface with this method, but it can be used on both magnetic and non-magnetic materials providing they are non-porous.

There are several types of penetrant system, this includes the following which are shown in a descending order of flaw detection sensitivity:

- Post-emulsifiable - fluorescent
- Solvent based - fluorescent
- Water based - fluorescent
- Solvent based - colour contrast
- Water based - colour contrast

Fluorescent penetrants require the use of an ultraviolet (UV-A) light to view indications, whilst colour contrast penetrants are viewed with the naked eye.

One of the most common *site* used penetrant systems uses solvent based colour contrast penetrants in aerosols. A typical sequence of operations on a steel test item is as follows:

1. Clean area using wire brush, cloth and solvent. On aluminiums, other soft alloys and plastics, wire brushing should not be used, as there is a danger that surface breaking defects may be closed.
2. Apply penetrant - leave for 15 minutes. Colour contrast penetrants are normally red in colour and should remain on the part long enough to be drawn into any surface discontinuities. This time can vary from about ten minutes to several hours depending on the type of material and size/type of defect sought.
3. Remove surface penetrant using cloth and solvent. Apply solvent to the cloth and not directly on to the work piece. Clean thoroughly.
4. Apply developer - leave for 15 minutes. The developer draws any penetrant remaining in any surface breaking discontinuities with a blotting action.
5. Interpret area. Any discontinuities are indicated by a red mark, e.g. line or dot against a white background. Fluorescent penetrants would show green-yellow when viewed with an ultraviolet (UV-A) light.

Magnetic particle inspection

This method of NDT may detect surface, and in certain cases, slight sub-surface discontinuities up to 2-3 mm below the surface. M.p.i. can be used on ferromagnetic materials only.

A magnetic field is introduced into a specimen to be tested, fine particles of ferromagnetic powder, or ferromagnetic particles in a liquid suspension, are then applied to the test area. Any discontinuity which interrupts the magnetic lines of force will create a *leakage field*, which has a north and south pole on either side of it. This attracts the ferromagnetic particles in great numbers. The discontinuity may show as a black indication against the contrasting background—usually white contrast paint—or as a fluorescent indication which is usually green/yellow against a dark violet background.

When m.p.i. is carried out using fluorescent inks the use of an ultraviolet (UV-A) light is necessary to cause fluorescence of the particles, although there is no need to apply a contrast paint.

NOTES

Fluorescent ink methods are more sensitive than black ink methods.

There are many ways to apply a magnetic field, e.g. a permanent magnet, coils, prods, cables and threading bar.

Listed below is a sequence of operations to inspect a weld, using a permanent magnet with black ink:

1. Clean area using wire brush and cloth plus solvent if necessary.
2. Apply a thin layer of white contrast paint.
3. When paint is dry, straddle the magnet over the weld.
4. Apply ink (1.25 to 3.5% particles to a paraffin base).
5. Interpret area.
6. To look for transverse defects, turn magnet approximately 90° and re-apply ink.
7. Interpret area.

Radiographic testing

Principles

Radiography is carried out using x-ray machines or artificial gamma sources (radio-isotopes).

X-rays or gamma rays pass through the object to be radiographed and record an image on a radiographic film on the opposite side. The radiation reaching the film will be determined by the objects thickness and density, e.g. lack of root penetration in a weld will increase the amount of radiation falling on the film in that area due to a reduction in thickness.

It is the wavelength of the radiation which governs its penetrating power; this is governed by the kilovoltage (kV) when using x-rays, and isotope type with gamma rays. The intensity of the radiation is governed by the milli-amperage (mA) when using x-rays, and by the *activity* of the specific isotope with gamma. Activity is measured in Curies (Ci) or gigabecquerels (GBq).

A *negative* is produced when the film is processed. The thin areas of an object will be darker than the thicker areas, therefore most weld defects will show up dark in relation to the surrounding areas; exceptions are excess weld metal, spatter, tungsten and copper inclusions.

Radiographic quality

An overall assessment of radiographic quality is made by the use of *image quality indicators (IQI's)*; these usually consist of seven thin wires decreasing in thickness. IQI(s) are pre-placed on the weld being examined and therefore show on the radiographic image. The more wires visible the better the flaw detection sensitivity is likely to be.

The *density*—degree of blackness—of a radiograph is also measured by using a *densitometer* to ensure it lies within a specified range for optimum quality.

Advantages and disadvantages

X-radiography requires bulky and expensive machinery in comparison with gamma radiography, but x-radiography generally produces better quality radiographs and is safer. X-ray machines can be switched on and off, unlike gamma sources which permanently produce radiation and therefore require shielding when not in use.

A major disadvantage with radiography is that it will only detect defects which have significant depth in relation to the axis of the x-ray beam—roughly over 2% of the wall

For x-radiography 150-300 kV is typically used on steel weldments up to approximately 40 mm total thickness.

Cobalt 60 (Co60) has a very high penetrating power—very short wavelength—and can be used on materials up to 200 mm thick. Iridium 192 (Ir192) is commonly used on steel weldments up to 50 mm thick; this therefore produces radiation with a longer wavelength than Co60.

NOTES

Sometimes two crystals are used, one to act as a transmitter of ultrasound and the other to act as a receiver.

thickness in the same axis as the x-ray beam, i.e. radiography will not usually detect plate laminations. lack of inter-run fusion or cracks perpendicular to the x-ray beam.

A major advantage of radiographic testing is that a permanent record is produced, i.e. the radiograph.

Ultrasonic testing

This method uses the ability of high frequency sound waves, typically above 2 MHz (2,000,000 c.p.s.), to pass through materials.

A *probe* is used which contains a piezo electric crystal to transmit and receive ultrasonic pulses. Ultrasound hitting any air interface, or an interface with a different material density, which is perpendicular to the ultrasonic beam is reflected back and displayed on a cathode ray tube (c.r.t.). The actual display relates to the time taken for the ultrasonic pulses to travel the distance to an interface and back, i.e. longer the time, the further away the interface.

An interface could be the opposite side of the plate, therefore wall thickness measurements can easily be made.

Lamination checks are easily carried out using ultrasonic methods (opposite to radiography). Welds can be tested using *angle* type probes, although this requires more operator skill to apply and interpret results. Defects in welds usually can be located but the type of defect is sometimes difficult to identify.

To detect a linear defect with radiography, the defects must have depth in line with the radiation beam; the opposite is true for ultrasonic flaw detection, i.e. when using ultrasonic testing the defects should ideally have their major face at 90° to the axis of the ultrasonic beam.

For the ultrasound to enter a material a couplant must be introduced between the probe and the specimen, e.g. grease, oil, glycerine or water, because ultrasound does not travel very well through air.

Ultrasonic equipment is quite portable, but one major disadvantage with most of the equipment used is that no permanent record of results is produced. Equipment that is able to record results is currently expensive.

Eddy current testing

Eddy current testing uses the electromagnetic induction of electrical currents—eddy currents—in a material. The currents are affected by any section change in the material, e.g. the presence of defects. These current changes are detected by the test instrument, often by the use of a probe which induced the currents initially, they are then displayed on a meter or a cathode ray tube (c.r.t.).

Eddy current testing is quite versatile. It is used for coating thickness measurements, cladding thickness measurements and alloy sorting as well as flaw detection.

Eddy current testing is able to detect sub-surface discontinuities, but the depth of eddy current penetration is limited. It is excellent for surface flaw detection, but for all types of testing, can be only used on conductive materials; both magnetic and non-magnetic.

Many different types of probe attachments are available, these include: internal bobbin-type coils, external coils, knife edge probes and many unique designs for specific applications.

NOTES

Castings are formed by pouring molten metal from a ladle into a hollow mould. Cast material may be further processed, e.g. cast steel ingots may be rolled into slabs and then into plates. The mechanical properties of castings may be enhanced by heat treatment. The range of castings is considerable from very small trinkets to very large complex components weighing hundreds of tons. Castings are made from a wide range of ferrous and non-ferrous materials.

Types of casting

Ingot casting

Ingots are used for further processing, e.g. rolled into slabs or bar product.

There are three types of steel ingot: rimmed, semi-killed and fully killed.

There are two basic types of mould: narrow end up (NEU) and wide end up (WEU).

Ingot technology is complex, therefore only a brief reference is being made to basic forms of ingots.

Rimming steel ingots

These ingots are produced by semi-killing the steel in the ladle with silicon (Si), just sufficient to allow oxygen to react with the carbon in the rim of the ingot producing blowholes of CO_2 and a pure iron rim free from carbon. The CO_2 blowholes weld up on rolling.

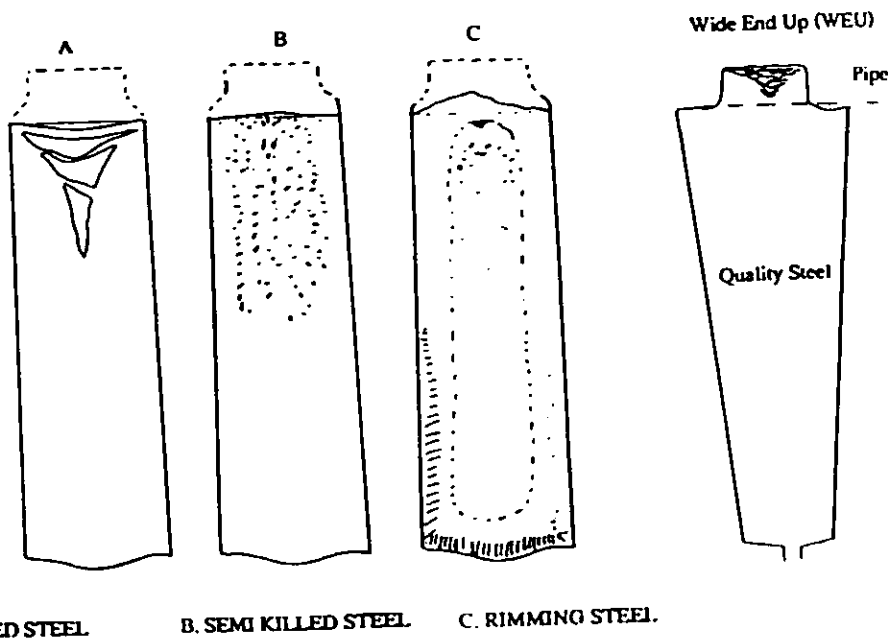
Mainly used for sheet, although used in plate form for non-critical applications.

Killed steel ingots

These ingots are produced by fully killing the steel prior to transfer of the liquid steel from ladle to ingot mould. All carbon/oxygen reactions are killed by either silicon or aluminium, or a combination of both. Aluminium also refines the grain structure producing fine grained steels.

All engineering grades of steel, high alloy and tool steels are killed steels.

Killed means deoxidized.

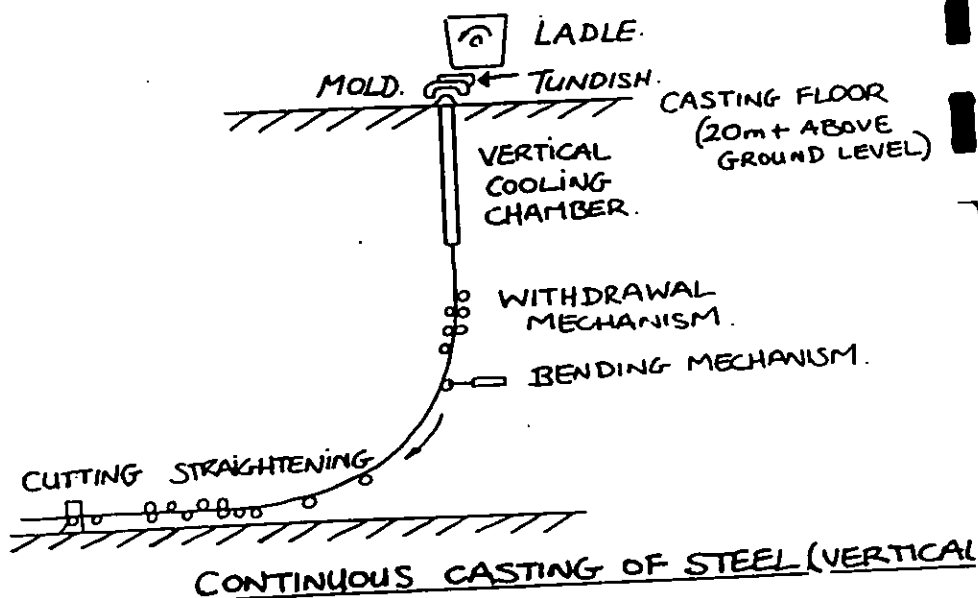


NOTES

Continuous casting

Continuous casting or concast is the process which produces continuous lengths of blooms or billets for re-rolling or further hot work. It is an alternative to the ingot method of production.

The diagram shows the ladle which is kept at the required temperature whilst being transferred from the steel furnace to its position at the top of the tower structure.



The metal is poured into a receiving tundish which is basically a refractory lined intermediate feed vessel where many impurities are removed.

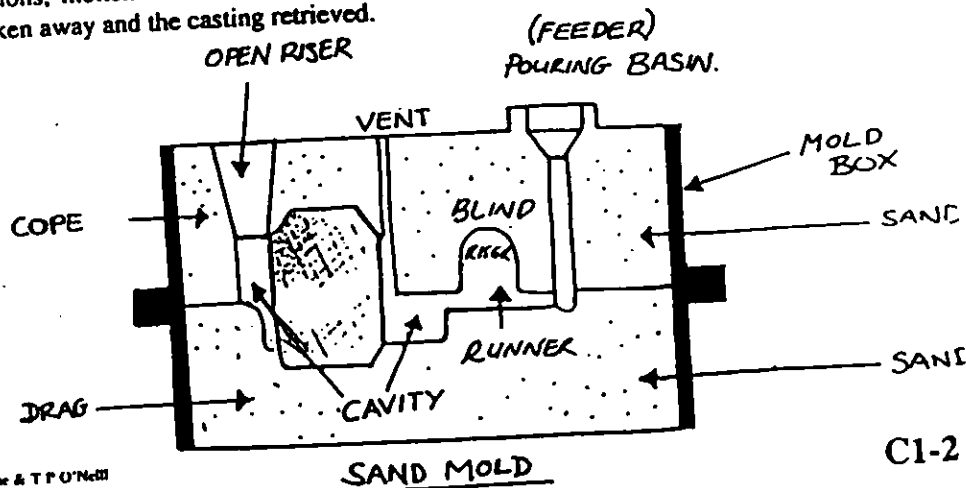
The molten metal is then allowed to travel down into copper moulds which have integral water cooling tubes which assist in the solidification process during its downwards path between pinch rollers.

Progression is maintained in the vertical plane and with guide rollers, the cast billet/bloom is directed into its ultimate horizontal plane. The length is continuously cut by flame torch automatically into its pre-programmed short length requirement.

This length is suitable for rolling or holding at an elevated temperature to be rolled as soon as is practicable.

Sand casting

This is the traditional method of casting, where a wooden pattern is placed in a two part compressed sand mould. The pattern is removed and by re-assembling the mould sections, molten metal can be poured into the void. After solidification the sand is broken away and the casting retrieved.



NOTES

Shell moulding

A ferrous or aluminium pattern is made resembling the cast item to be manufactured. The pattern is heated to between 150-370°C and has a coating of silicone applied which acts as a release agent. A fine sand mixed with a thermo-setting binder is then blown over the heated pattern to provide optimum coverage prior to placing into a sand box containing the same material. Further heating is applied to complete resin curing.

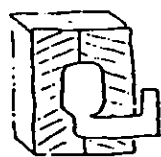
The shell is then taken from the pattern in two halves and suitably mounted to receive molten material to produce castings within very fine tolerances.

Investment casting

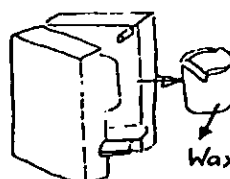
The pattern, made of wax or plastic, is dipped into a slurry of refractory material to make a mould, this is repeated many times to build up its thickness.

When the mould is dry in air, it is heated to 90-175°C in an inverted mode to melt the foundation wax or plastic. The mould is then fired at 650-1050°C. If many similar items are required, many moulds can be placed together on a tree feeder stem.

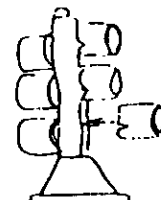
Investment casting is ideal for intricate shapes especially when using high melting point materials. No finishing work is required due to the accurate finishes obtained.



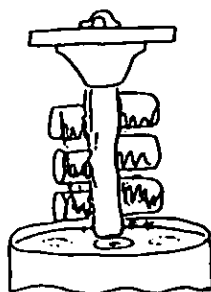
Injected wax pattern.



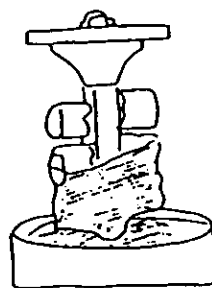
Ejected pattern.



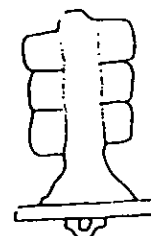
Tree Assembly.



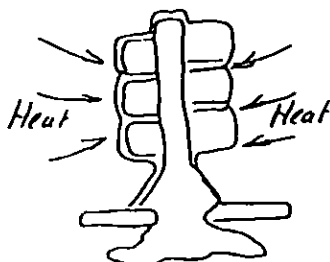
Slurry Coating



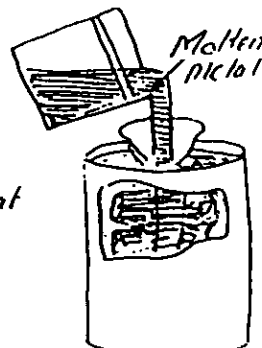
Resin Coating (Stucco)



Completed mold.



Pattern meltout



Pouring



Shakeout



Casting



Pattern

NOTES

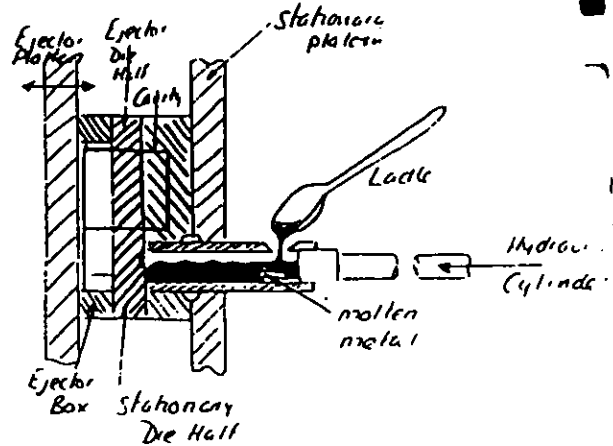
Die casting

Die casting is primarily used to make castings with aluminums, magnesium alloys and low melting point materials.

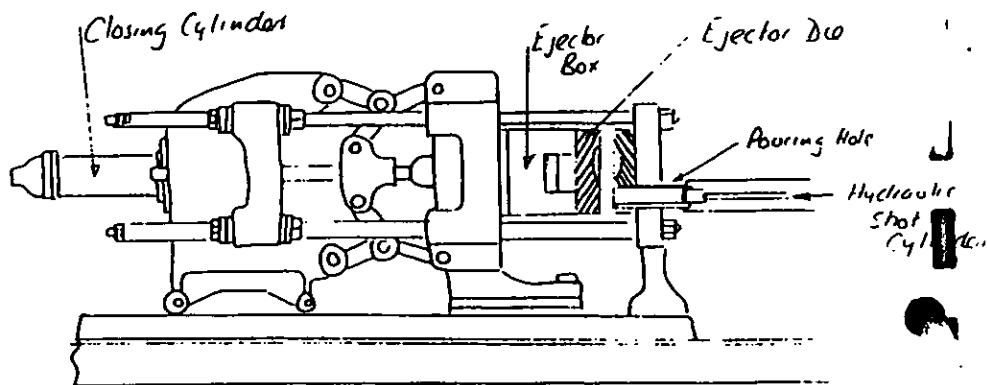
The molten metal is forced into the die cavity of special steel dies at pressures between 0.7-700 MN/mm².

There are two types of process:

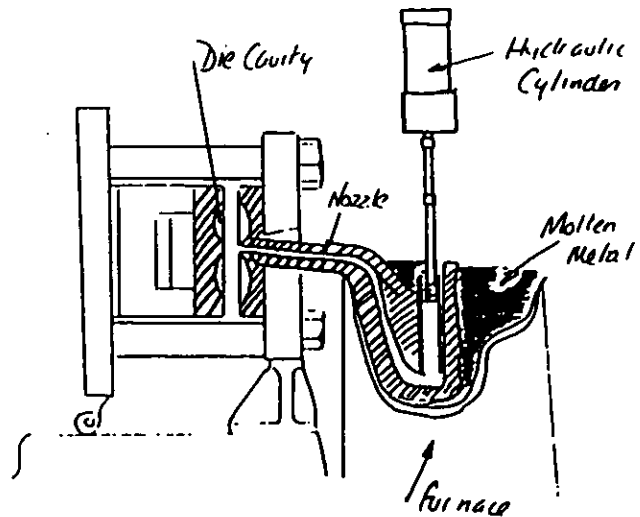
1. Hot chamber process - a piston forces the hot molten metal into the die cavity and maintains pressure until the metal solidifies. Ideal for zinc, tin and lead materials.
2. Cold chamber process - molten material is teemed into a cold piston aperture and then is injected into initially cold die-plates. Ideal for aluminium, magnesium alloys and copper base alloys.



Die Casting - Cold Chamber



Die Casting Machine



NOTES

Casting defects

The following defects are present in the material before any further processing operations such as forging or rolling have begun all casting defects are therefore inherent.

Porosity

This is formed by gas which is insoluble in the molten metal. The gas is trapped within the metal when it solidifies and remains in the form of spherical or tubular cavities.

Airlocks

A cavity formed by air which has been trapped in the mould by the metal during pouring.

Blowholes

These are small holes in or on the surface of the casting. They are caused by gas evolution from the decomposition of grease, moisture etc., but not from the mould itself.

For example, during the sand casting operation, moisture from the mould produces steam, this is normally forced through the mould due to the absorbent nature of the sand, but sometimes the steam cannot get through to the outside and is forced back into the casting, blowing holes in the casting surface.

Non-metallic inclusions

Non-metallic inclusions are impurities such as slag, oxides and sulphides, which exist in the molten metal and finally the solidified metal.

Pipe/shrinkage defects

This is a cavity in the centre of the ingot/casting caused by shrinkage during solidification. A primary pipe is surface breaking; secondary pipes are those which exist subsurface. The top of an ingot casting is removed to get rid of the primary pipe.

Other shrinkage defects may occur in steel castings where there is a localized variation in section thickness. Shrinkage defects are not normally associated with gas, but a high gas content will magnify their extent.

Inter-dendritic shrinkage: very small shrinkage cavities associated with dendrite solidification.

Segregation

Segregation is chemical heterogeneity, or the non-uniform distribution of the alloys or impurities. Pure metals do not exhibit segregation.

In carbon steels the elements which segregate are those that are either insoluble or form lower freezing point complexers, e.g. sulphur, phosphorus, carbon, manganese and silicon.

Cold shuts

A cold shut is an area of lack of fusion which may be surface breaking or subsurface in a casting. Cold shuts may result from splashing, surging, interrupted pouring, or the meeting of two streams of molten metal coming from different directions.

Hot tears (cracks)

Cracks caused by non-uniform cooling resulting in stresses which rupture the surface of the metal while its temperature is still in the brittle range. They appear as ragged lines of variable width and numerous branches. The tears may originate where stresses are

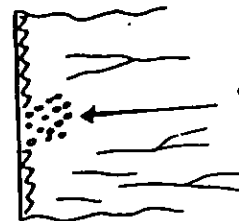
NOTES

set up by the more rapid cooling of thin sections that adjoin heavier masses of metal, which are slower to cool. Curved surfaces and corners tend to promote hot tearing.

POROSITY



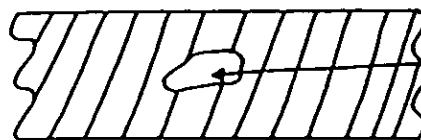
INGOT/CASTING SURFACE



GROUP OF SMALL
GAS PORES

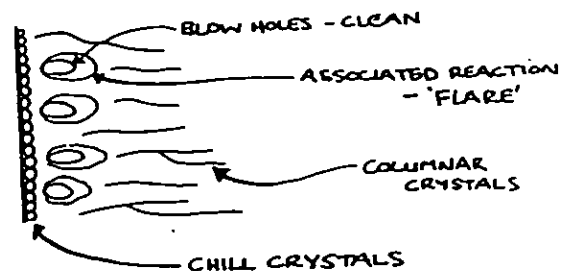
SECTION THROUGH INGOT/CASTING

AIR LOCK



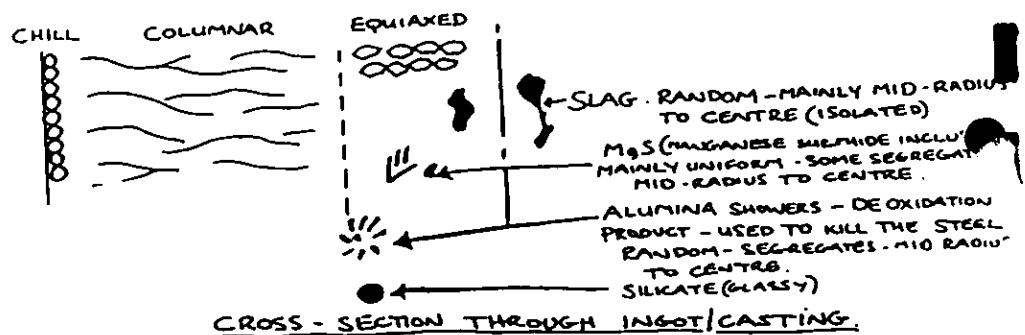
CAVITY - MAYBE 'CLEAN'
OR HAVE LIGHT SURFACE
OXIDATION.

BLOW HOLES



SECTION THROUGH INGOT/CASTING

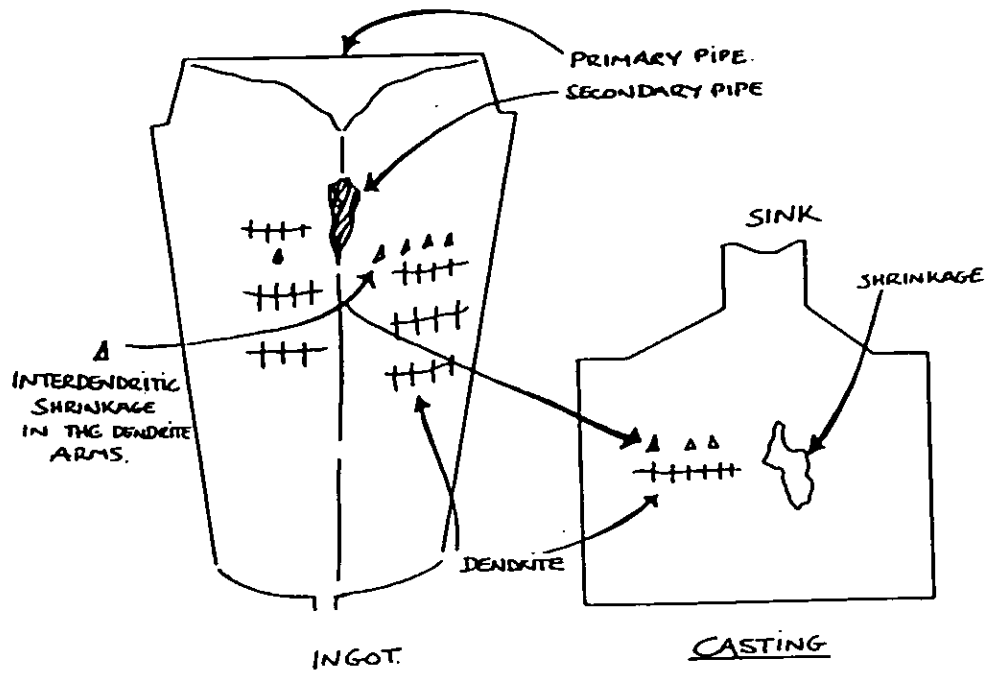
NON-METALLIC INCLUSIONS.



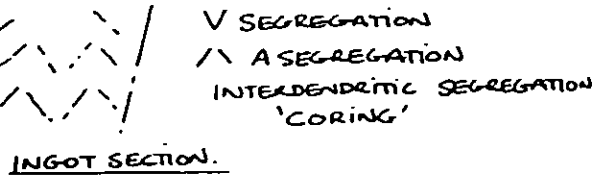
CROSS - SECTION THROUGH INGOT/CASTING

NOTES

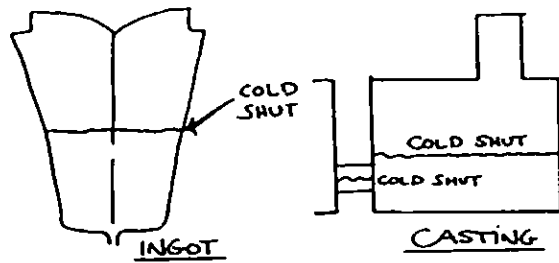
PIPE SHRINKAGE DEFECTS.



SEGREGATION.



COLD SHUT



HOT TEARS



NOTES

A wrought product is a worked product, primarily produced by hot working, e.g. forging or rolling, although cold working is possible in some cases.

Forging

Forging is one of the oldest forms of metal working processes known to man and is simply illustrated by the blacksmith using a hand held hammer and anvil working with hot metal supported by tongs.

At the other extreme, very precise pairs of dies may be used with hydraulic presses to produce precision finished components.

Forging is often used when strength and toughness are needed from the components. Many basic components, e.g. nuts, bolts, rivets, are mass produced by forging.

Because the base material is more malleable at high temperatures, hot forging is easier to perform. Cold forging requires much greater forces to distort the material to shape.

Forging can be carried out by many methods, some of which are listed below:

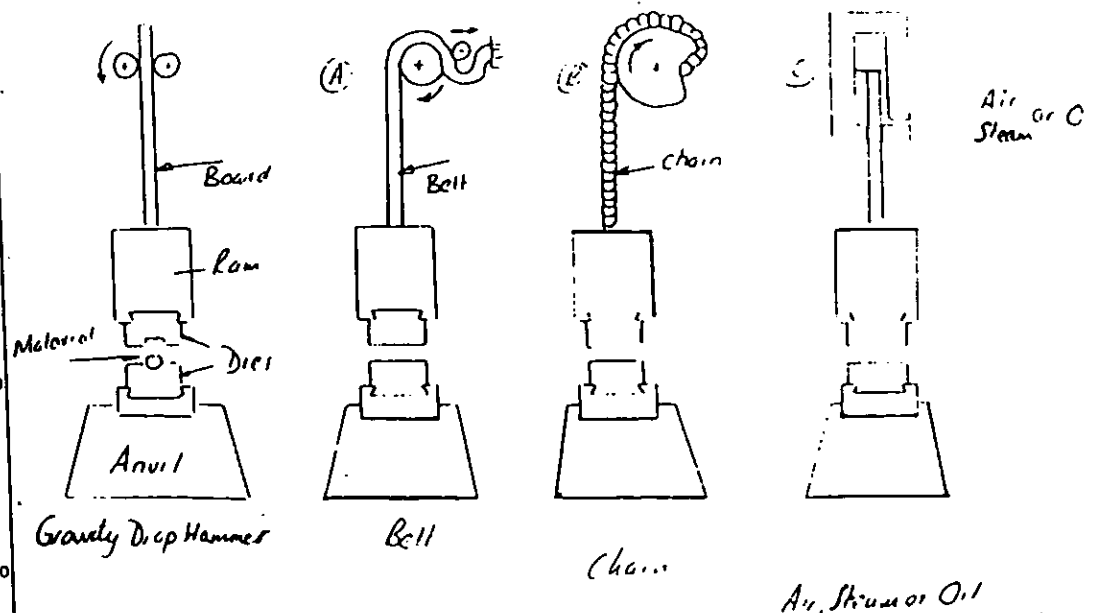
Hammer forging

For components to be used in industry, hand forging is rarely used; however, automatic hammer processes may be encountered.

Hammer forging uses the energy derived from the mass and velocity of the hammer contacting the stationary work piece.

There are two main types of hammer forging used in industry:

1. Gravity drop hammers (drop forging) - this is where a forging ram is raised against gravity by chain, belt, air, steam, etc. and is then allowed to fall freely to contact the workpiece.
2. Power drop hammers - these are similar to the above but the power (down stroke) is a pressurised ram that intensifies the impact. The ram is air, steam or hydraulically operated.

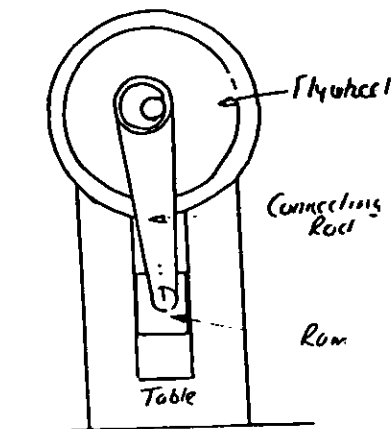


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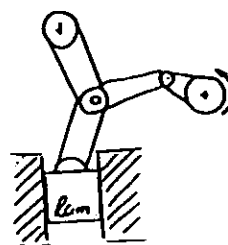
Press forging

Press forging is when force is imparted by a pressing action; the specific methods used are:

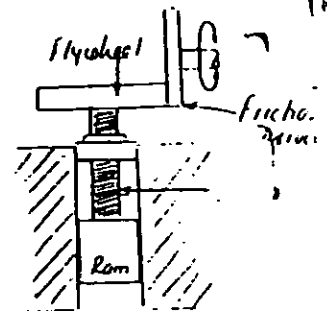
1. Mechanical presses - these have a crank or eccentric type of actuation. They are limited by the inherent length of stroke but high forces can be generated. Special component dies are fitted to meet component manufacturing requirements.
2. Screw press - this uses the stored energy of a flywheel or centrifugal mass; the mass of flywheel or centrifugal mass is a limitation in itself. This system uses die inserts and is only suitable for light work.



Eccentric Press
Slow operation.



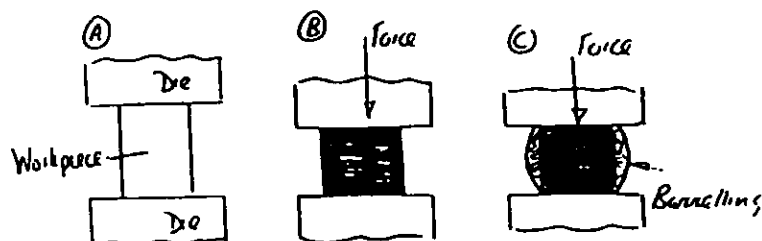
Knuckle Press



Screw Press

Open die forging

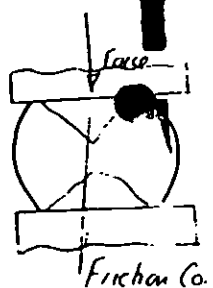
Two flat dies are placed in the two forging faces and a suitably heated section of material is placed on the lower die. The faces are brought together and the material is shaped by compression sometimes termed upsetting.



(A) Cylindrical Billet

(B) Uniform Deformation.

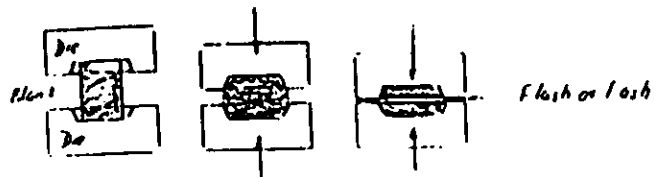
(C) Deformation with Friction.



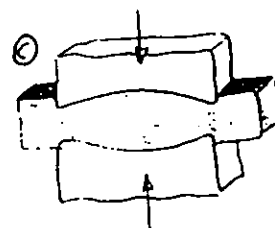
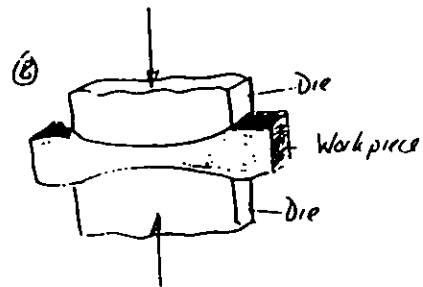
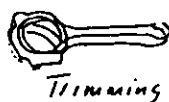
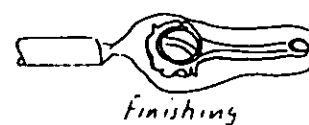
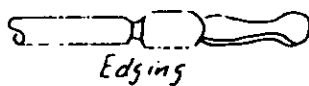
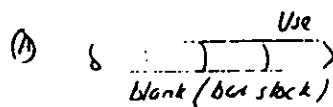
Closed die forging

Used when special shapes are required. A sequence of forging sets have to be used: the material is shaped, part formed, formed again, possibly pierced and finally trimmed, to produce components almost to size. Closed die forging produces excess metal called flash which has to be trimmed off.

NOTES



Die Forging



- (A) Stages of forging
 (B) Fullering
 (C) Edging

Cold forging

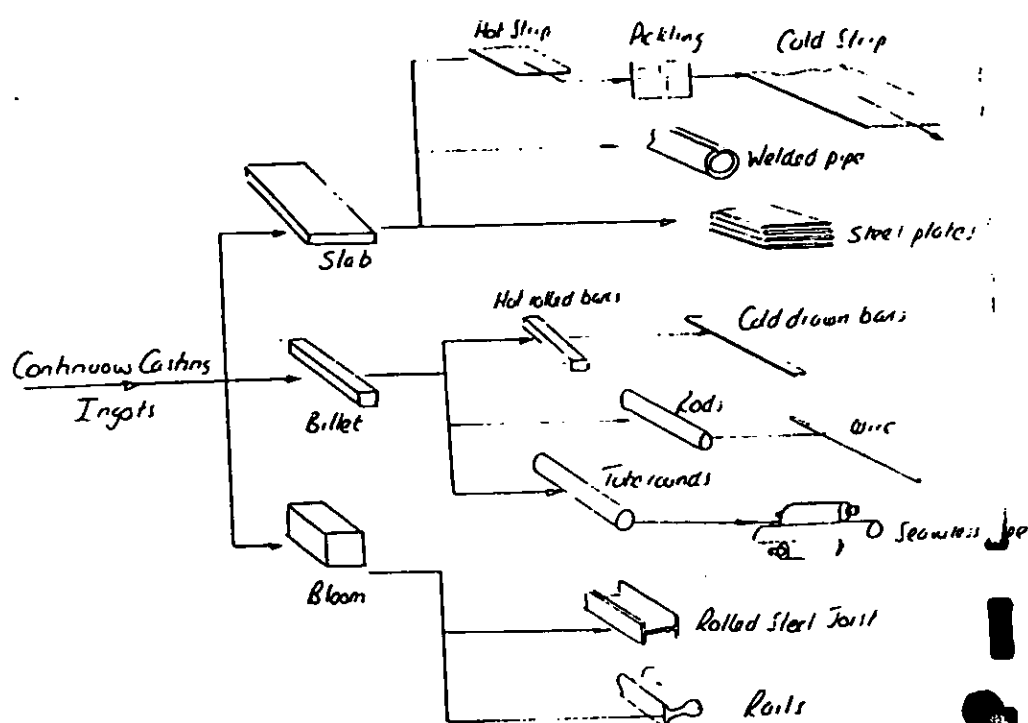
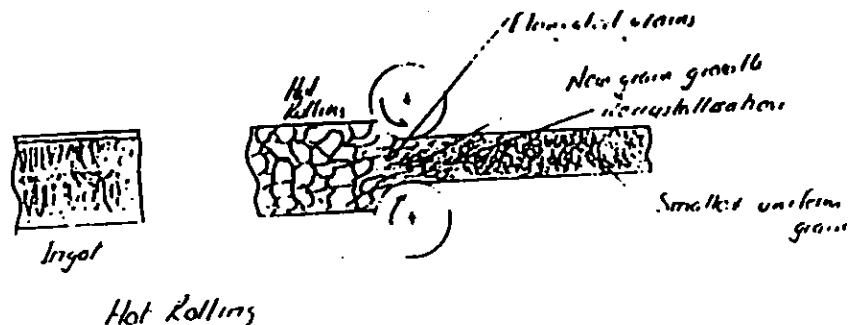
This produces a good surface finish and dimensional accuracy. Material must be capable of being cold worked.

Rolling

Rolling practice

Rolling is the process that follows the ingot or continuous casting stage. Hot rolling converts the initial coarse cast grain structure into the wrought structure which enhances ductility. Rolling may also close up any internal defects such as porosity.

NOTES



Blooms, billets and slabs

The following terms have been taken from BS 6562 : 1986 : Terms used in the iron and steel industry.

- Square bloom - Semi-finished product with sides generally greater than 120 mm.
- Rectangular bloom - Semi-finished product with cross sectional area greater than 14,400 mm² and with a ratio of width to thickness greater than 1:1 and less than 2:1.
- Square billet - Semi-finished product with sides generally equal to or greater than 50 mm and less than or equal to 120 mm.
- Rectangular billet - Semi-finished product with cross-sectional area equal to or greater than 2500 mm² and less than or equal to 14,400 mm² and with a ratio of width to thickness greater than 1:1 and less than 2:1.
- Round billet - Semi-finished product with diameter equal to or greater than 75 mm. (Up to 75 mm it is termed round bar).

NOTES

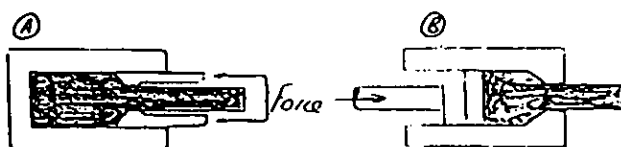
- Slab - Semi-finished product of thickness equal to or greater than 50 mm and with a width to thickness ratio equal to or greater than 2:1.
- Flat slab - Slab with a width to thickness ratio greater than 4:1.

Extrusion and drawing process

Extrusion

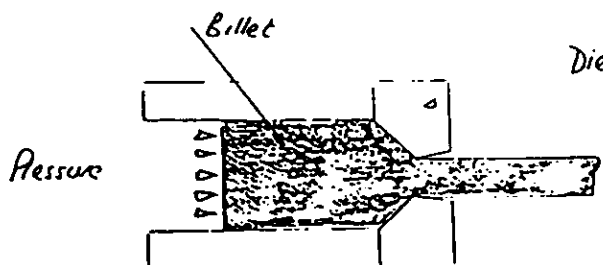
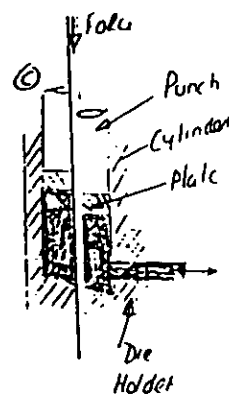
Extrusion is the process which pushes material through a shaped die. There are two main types of extrusion process:

1. Direct extrusion - a hot billet is placed in a chamber, then forced out under pressure through a die opening.
2. Indirect (or reverse) extrusion - the billet is held within a chamber, the die holder is then forced into the billet extruding the shaped section.



Types of Extrusion

(A) Indirect (B) Direct (C) Lateral



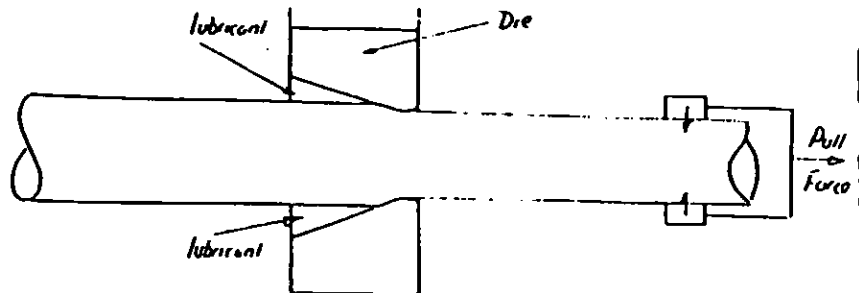
Extrusion is normally carried out at elevated temperatures—termed hot extrusion—to increase the ductility of the material and therefore the ease in which extrusion can be achieved.

After extrusion, a thin residual shell known as *skull* is sometimes left in the chamber. The existence of skull confirms that the extruded material is free of oxide.

NOTES

Drawing

Drawing is the process in which material typically round bar or rods pulled through reducing sized dies to produce small cross sections.



Rod, Tube or Wire Drawing

Wrought product defects

Laps

Forging laps are caused by metal being folded over and flattened but not fused onto the surface of the forging. Laps can be produced by using faulty or oversized dies.

Bursts

Forging bursts are surface or internal ruptures caused by processing at too low a temperature, excessive working or metal movement during forging.

Laminations (in flat plates)

Laminations are planar voids usually aligned parallel to the surface of the material. They may be the result of any original casting defect enlarged and flattened.

Slugs

A slug is a piece of foreign material which has been pressed or rolled into the wrought material.

Stringers (in bar stock)

As a billet is rolled into a bar section, any non-metallic inclusions are squeezed out into longer and thinner defects. These are called *stringers*.

Seams and laps (in bar stock)

During the rolling operation, faulty, oversized dies, surface cracks or any surface irregularities may cause laps or seams.

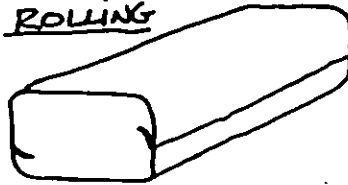
Banding

As the ingot is forged and rolled, the segregations are elongated and reduced in cross-section. If further processing is carried out, they may appear as very thin parallel lines or bands and is generally known as banding. Banding is not usually considered significant.

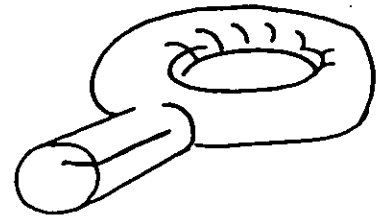
NOTES

LAPS.

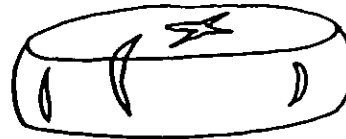
ROLLING



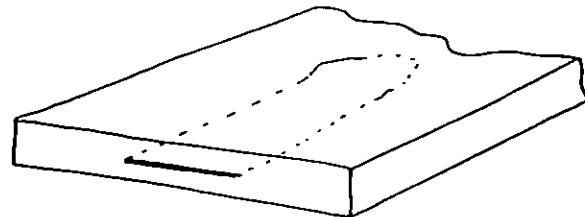
FORGING LAP



BURST

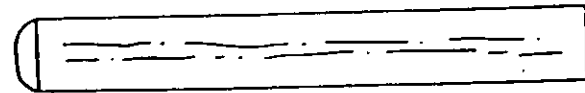


LAMINATIONS - PLATES



STRINGERS

INTERNAL.



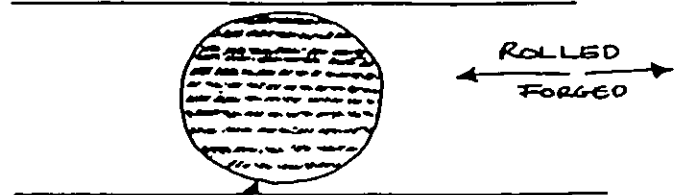
SECTION THROUGH ROD.

SEAMS, ROKES ETC. BILLET BAR ETC.



BANDING

SECTION ROLLED/FORGED.



MICRO STRUCTURE X 50.

Product Technology

Specific Theory (No Welding) - QP-PRT-E1

1. What is a *chill* used for?
2. Where on castings are you most likely to find *sinks*?
3. Which process is associated with *flash lines*?
4. What is a *planar* defect?
5. What is *annealing* and why is it sometimes purposely carried out?
6. What do you understand by *upset forging*?
7. Is it true to say that incorrect fitting moulds could cause flash lines?
8. Would heat treatment prior to a forging process affect final grain size?
9. Is it possible for the forging process to close and *weld* defects caused during casting?
10. List three types of service induced crack.
11. What do you understand by the term *fatigue* when related to components in service?
12. What is *banding*?
13. What is a *chaplet* used for?
14. Describe what you understand by the term *concast*?
15. Describe how *laminations* are produced.
16. What is a *cope* and *drag* used for?
17. Where are *blowholes* found on castings?
18. Are *chills* used internally, externally or both?
19. How does *killed* steel differ from rimmed steel?
20. How is a *cold shut* formed?
21. Which process is associated with *stringers*?
22. What is an *equiaxed* defect?
23. Which casting process is likely to give the best surface finish?
24. What is the difference between a *primary pipe* and a secondary pipe in a casting?
25. What is meant by a *wrought product*?

**PENETRANT
TESTING**

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1 PENETRANT TESTING

1.1 Overview

Penetrant testing uses the forces of capillary action to detect surface breaking defects only. It is impossible to detect defects which do not break the surface with this method, but it can be used on a wide variety of non-porous materials including both magnetic and non-magnetic metals. Normally on ferromagnetic materials it is preferable to use magnetic particle inspection.

There are various penetrant systems including the following, listed in a general order of sensitivity:

1. Post-emulsifiable - fluorescent
2. Solvent based - fluorescent
3. Water based - fluorescent
4. Post-emulsifiable - visible
5. Solvent based - visible
6. Water based - visible

Fluorescent penetrants require the use of an ultraviolet (UV-A) light to make the indications fluoresce so that they may be detected, whilst colour contrast (visible or dye) penetrants are viewed under daylight or white light conditions.

One of the most common *site* used penetrant systems uses a solvent based colour contrast penetrant in an aerosol, a solvent cleaner and a solvent based developer.

A *typical* sequence of operations on a steel pipe is as follows:

1. **Clean area using wire brush, cloth and solvent.**
On aluminums, soft alloys and plastics, wire brushing should not be used, because there is a danger that surface breaking defects may be closed.
2. **Apply penetrant - leave for 15 minutes.**
Colour contrast penetrants are normally red in colour and should remain on the part long enough to be drawn into any surface discontinuities. This time can vary from about ten minutes to several hours depending on the specification or manufacturers requirements.
3. **Remove surface penetrant using cloth and solvent.**
Apply solvent to the cloth and not directly on to the work piece. Clean thoroughly but try to avoid removing any penetrant from any surface breaking discontinuities.
4. **Apply developer - leave for 15 minutes.**
The developer which is usually white, draws out the penetrant remaining in any surface breaking discontinuities with a blotting action. Development times vary from approximately ten minutes to one hour depending on the specification or manufacturers requirements.
5. **Interpret area.**
Any discontinuities will show as a red mark, e.g. line or dot, against a white background. Fluorescent penetrants would show green-yellow when viewed with an ultraviolet (black) light against a deep violet background.
6. **Post clean.**
7. **Report.**

1.2 Penetrant types

1.2.1 Colour contrast penetrants

These contain an intense dye, usually red, in an organic carrier fluid, they provide high contrast against a white background and are visible in normal daylight or white light conditions.

These penetrants are ideal for site use because of the light conditions, i.e. there is no need to darken the viewing area¹, it is also not necessary to have an electrical supply to operate a UV-A² light, although a torch or other source of white light may be required in certain circumstances.

Colour contrast penetrants are less sensitive in comparison with fluorescent systems.

1.2.2 Fluorescent penetrants

These contain additives which fluoresce usually a bright green-yellow colour when subjected to the radiation emitted from a UV-A light. Fluorescent penetrants produce much higher contrast and therefore have a greater sensitivity on fine (tight) defects in comparison with colour contrast penetrants.

They are more suited to the fabrication shop or factory situation where an electricity supply is readily available and lighting conditions can be easily controlled. Dark viewing conditions are required to give high contrast, however they can be, and indeed are, used on site.

1.2.3 Further sub-divisions

The above penetrant types can be further sub-divided by the method used to remove excess penetrant from the surface being tested.

1.2.3.1 Water washable penetrants

These contain an emulsifier to make the penetrant removable on the application of water. This type of penetrant is usually the least sensitive on fine defects and there is also the greatest risk of washing penetrant out of surface cavities during post surface cleaning. However, being solvent free it has the advantage of producing the least reactions on the operators skin and is also the least toxic for use in enclosed situations.

1.2.3.2 Solvent removable penetrants

Solvent removable penetrants contain solvent based dyes which are more *searching* than the water based types and are commonly used, especially for site work, as they form the basis of the aerosol powered portable penetrant kits. There is also less risk that penetrant will be removed from defects during cleaning compared to the removal of water washable penetrants.

1.2.3.3 Post-emulsifiable penetrants

These penetrants have the penetration advantages of solvents and allow better control of the water based washing process, they have the disadvantage of an extra time consuming stage in which the emulsifier has to be applied at the end of the

¹ There is a requirement to darken the viewing area when using fluorescent penetrants.

² UV-A is a term which has replaced the old term *black light* and means ultraviolet radiation having a wavelength in the region 315 nm to 400 nm, used for exciting fluorescence.

contact time and before the excess surface penetrant can be removed. They are particularly suited to fluorescent dyes, thus providing the most sensitive penetrant system.

There are two types of post-emulsifiable penetrants: hydrophilic and lipophilic.

1.3 The properties of penetrants

Some of the properties of a penetrant will ultimately affect its ability to detect surface breaking discontinuities; a penetrant has the following properties:

1.3.1 Capillary action

The penetration capability of a penetrant is dependant upon its capillary action. Capillary action can be demonstrated by vertically inserting a small diameter tube into a liquid bath. The liquid will rise up the tube until the upward capillary pressure and the downward air pressure equalise.

If a number of different diameter tubes were used, it would be seen that the capillary pressure increases with a reduction in diameter and the liquid climbs further up the tube, this is quite significant and it enables penetrants to enter tight surface breaking discontinuities as fine as 1 μm in width.

The capillary pressure can be determined by the following formula:

$$P = \frac{2S \cos \theta}{D}$$

where:

P = capillary pressure
S = surface tension of the liquid
D = tube internal diameter
 θ = contact angle

1.3.2 Surface tension

The higher the surface tension, the higher the capillary pressure and therefore the greater the penetrating ability.

1.3.3 Wetting ability

The ability of a penetrant to wet a surface should be high. Wetting ability increases as the contact angle in a capillary tube decreases.

1.3.4 Viscosity

The viscosity of a penetrant governs the speed at which it will enter a surface breaking discontinuity. The viscosity should be of a moderate nature. If the viscosity of the penetrant is too low it will be easily removed from defects during cleaning operations, if the viscosity is too high the rate of entry into a discontinuity will be too slow.

1.3.5 Solubility/solvent ability

In order for excess penetrant to be removed from the surface it needs to be soluble in either water, solvents or emulsifiers. This requirement needs to be controlled because excessive solubility may allow complete penetrant removal. Solubility will decrease as the temperature drops.

A penetrant consists of a dye, possibly an emulsifier, and other chemicals to improve sensitivity and other properties. A high solvent ability is necessary to dissolve all these constituents and hold them together in correct concentration over a temperature range covering all climatic conditions. It is also beneficial if the penetrant has the ability to dissolve contaminants present in defects.

1.3.6 Tolerance to contaminants

A high tolerance to contamination is necessary due to the possible existence of water, oil, grease etc. on the surface being tested. The penetrant must be able to accept these, assuming they are minute traces, without its own chemical balance being affected.

1.3.7 Density/specific gravity

Most penetrants are hydrocarbons and have a density of less than 1 g/cm^3 . Most contaminants, including water and solids, will sink in penetrant, this is particularly useful when using a penetrant tank for dipping components.

1.3.8 Volatility

In order to prevent rapid evaporation, which would result in an increase in viscosity, a low level of volatility is required.

1.3.9 Flammability

Ideally the solvents used in penetrant testing should be non-flammable, *halogenated hydrocarbons*, which are non-flammable, may be used, but these can adversely react with certain test piece materials and many are also considered to be carcinogenic.

1.3.10 Flash point

The flash point is the temperature at which the solvent vapour when mixed with air is liable to ignite if a source of ignition is introduced; the higher the flash point the greater the safety. Most penetrants have flash points above 55°C and this is considered as adequate for most situations.

1.3.11 Chemical inertness

To be completely inert a chemical when applied to a surface must not produce any new reaction, however some penetrants are based on halogenated hydrocarbons which, if left on the surface after testing, will attack nickel alloys, stainless steels and certain other materials.

Water washable penetrants contain alkaline emulsifiers which, if left on the surface after testing, will corrode aluminium especially in high humidity environments.

1.3.12 Toxicity

The poison value of a solvent is expressed in *parts per million (p.p.m.)* and each solvent has its own maximum concentration in air in accordance with the COSHH Regulations.

1.4 Test procedures

1.4.1 Pre-cleaning

Pre-cleaning is an essential operation to remove contamination such as water, oil, etc. to ensure penetration of the penetrant into surface breaking discontinuities.

Acids or alkalis on the test surface degrade the fluorescence of fluorescent penetrant indications.

Pre-cleaning is most commonly carried out by washing the test area with a suitable solvent, other suitable methods include solvent vapour degreasing and steam cleaning, but these methods require the use of bulky equipment and are not often used for site testing.

Abrasive methods should be used with caution as they may peen over the surface of any discontinuities, thereby closing them off and stopping, or at least reducing, the entry of the penetrant. If mechanical cleaning is absolutely necessary it should ideally be followed by an acid etch to remove the peened over surfaces.

It should be appreciated that the prime reason for the failure of the penetrant process to provide indications of existing surface breaking defects is incorrect or inadequate pre-cleaning.

The test surface must be dry before the application of the penetrant.

1.4.2 Penetrant application

Penetrant can be applied to the surface by one of the following methods.

- a. **Immersion** - This method of application is commonly used where large numbers of small components are to be examined in a factory or workshop environment. It is also common on single components which are small enough to fit into the tank.

It is only necessary to quickly dip the components in and out of the tank then set them aside to drain, the penetrant viscosity and wetting ability should be adequate to prevent draining from occurring too fast.

- b. **Flooding** - Penetrant may be poured over the component, or components, to be tested. The excess penetrant would normally drain off into a tank to prevent wastage.
- c. **Brushing** - May be used on a variety of components, especially those of a complicated shape. It is sometimes used on site work.
- d. **Spray** - Probably the most common technique for *in situ* inspection. The penetrant may be applied by aerosol, manual pump, conventional spray or electrostatic spray.

1.4.2.1 Penetration time - contact time

The *penetration time* is defined in the *BS 3683 : Part 1* as 'the time allowed for penetration of discontinuities by the penetrant', the *contact time* is defined as 'the time during which the penetrant is in contact with the component under test', both these terms are essentially the same; the contact or penetration time is primarily dependant upon the following factors:

- a. The type of penetrant, e.g. water or solvent based.
- b. The composition of the material being examined.
- c. The nature and size of the defect being sought.
- d. The ambient temperature conditions.

Unless it is a special penetrant, temperatures below approximately 15°C will retard the penetration effect of the penetrant. The ideal application temperature is around 20°C, a drop of 5°C will require a 50% increase in contact time, a drop of 10°C will require a 100% increase in contact time; applications of penetrant below 10°C should be avoided.

The nominal contact time will normally be indicated by the penetrant manufacturer and is usually 15-30 minutes. Contact time can only really be determined by taking all the previous factors into consideration and applying an initial trial and error test; the smaller the defect to be detected the longer the contact time required. In accordance with the *BS 6443*, contact times should not be less than 10 minutes unless manufacturer states otherwise.

1.4.3 Removal of the excess penetrant

At the end of the contact time any remaining penetrant on the surface under examination has to be removed, but penetrant which has penetrated defects should be left undisturbed. Excessive cleaning may dilute or even remove penetrant completely from defects.

The method of excess penetrant removal depends upon the type of penetrant in use and the size and condition of the surface under test.

1.4.3.1 Water washable penetrants

Water sprays may be used but they should not be severe or prolonged; they should consist of coarse water droplets directed at the component at an angle of approximately 45°, but not down the longitudinal axis of any defects or potential defects. The *BS 6443* states a maximum water pressure of 2 bar (approximately 30 p.s.i.) with the spray nozzle not closer than 0.3 meters.

Immersion in an agitated wash is another method of excess penetrant removal for water washable penetrants. The use of water soaked or dampened cloths is generally avoided.

1.4.3.2 Solvent removable penetrants

The surface should first be wiped with a clean dry cloth to remove excessive penetrant, followed by wiping with a solvent dampened cloth, then a final wiping with a clean dry cloth again. Direct spray application should not be used as this increases the possibility of removing penetrant from defects.

1.4.3.3 Post-emulsifiable penetrants

When post-emulsification is necessary to make the excess penetrant water washable, it must be carefully timed and the manufacturers instructions consulted for accurate directions, although experimentation with representative test pieces will give the ultimate assurance of correct emulsification times.

There are two methods for removing excessive post-emulsifiable penetrant from the test surface; the following procedures are taken from the *BS 6443*:

1. Aqueous removal (hydrophilic process).

Aqueous removers supplied as concentrates shall be diluted in accordance with the manufacturers instructions, and the removal process shall be carried out as described below.

First aqueous wash (optional). Wash surfaces of the components under the conditions given by a water spray nozzle or an air/water spray gun to remove obvious excess penetrant.

Application of aqueous remover. Immerse the components completely in the aqueous remover or apply the remover by spraying. Keep the period of contact with the remover to a minimum consistent with an acceptable background and do not exceed the maximum period of contact specified by the manufacturer. Apply the second aqueous wash immediately after the specified contact period with the remover has elapsed.

Second aqueous wash. Subject the components to an agitated aqueous wash or, for small components, to a spray-wash for a period of 30 seconds to 2 minutes.

2. Post-emulsifier (lipophilic process)

Application of emulsifier. Apply the emulsifier by immersion and draining, spraying or flow-on in accordance with the manufacturers instructions. Do not apply the emulsifier by brush. Take care to avoid local entrapment of the emulsifier caused by the geometry of the component. Keep the period of contact with the remover to a minimum and do not exceed the manufacturers recommended maximum period.

Aqueous wash. Immediately after the contact period with the emulsifier has elapsed, immerse the components in an agitated aqueous wash, or spray-wash small components for a period of at least 30s. Maintain the temperature of this aqueous wash between 15°C and 30°C.

1.4.4 Drying

Prior to the application of the developer the component should be thoroughly dried, this is best done with a warm or cold air blast. If the developing is to be carried out by the use of an aqueous developer this stage can be omitted.

1.4.5 Developing

The action of a developer is similar to blotting paper. It will draw the penetrant from any surface opening and will reveal the existence by a resulting stain.

It is important to apply the developer evenly and thinly; a thick layer may conceal a defect that is only holding a small volume of penetrant.

Developers exist in the following forms:

- a. Dry powder.
- b. Liquid - aqueous suspensions.
- c. Liquid - aqueous solutions.
- d. Liquid - non-aqueous (solvent based)

The BS 6443 states the following with regard to the application of developers:

1. *Dry powder developers.* Apply the developer immediately after drying the component using any of the following techniques:

- a. Dust storm.
- b. Electrostatic spraying.
- c. Flock gun.
- d. Tumbling.
- e. Insufflator.
- f. Fluidized bed.

Note: In general, dry powder developers should not be used with colour contrast penetrants because of the resulting lack of contrast between the background and the indication.

2. *Liquid developers (aqueous liquid).* Apply the developer by method (a) or (b) below, as appropriate, directly after the aqueous washing removal steps and subsequently dry the components.

- a. *Suspensions in water.* Immerse the components in an agitated suspension for at least 30 s and withdraw them in such a manner that heavy accumulations in the corners and other regions of the components are avoided prior to drying.
- b. *Solutions in water.* Apply the developer either by immersing the components in it for a period of at least 30 s, or by wet spray, or by brush, or by flow-on. Allow excess developer to drain from the components and take care to guard against the retention of reservoirs of developer in the surface features of the components prior to drying.

3. *Liquid developers (non-aqueous liquid).* Thoroughly agitate the developer prior to use.

Where a non-aqueous liquid developer is to be used as part of a colour contrast penetrant system, apply, by spraying, a thin regular coating of developer (after evaporation of the volatile carrier) sufficient to obscure the surface of the component. Where a non-aqueous liquid developer is to be used as part of a fluorescent penetrant system, apply, by spraying, a coating such that the surface texture of the component is still discernible through the layer of developer.

Note: Application of developer by means other than spraying causes loss of indications by masking or by leaching-out of penetrant from defects.

Aqueous developers have the disadvantage of being slow to dry and often give uneven coatings. Dry powders also tend to result in uneven coatings. Non-aqueous developers, which are spray applied, usually give even coatings, but have a disadvantage when used in enclosed spaces due to a build up of solvent vapour.

Due to the uneven results obtained, the use of a brush applied developer is not normally recommended.

If the developer dries and exhibits a slight pink colour when used with colour contrast penetrants, or slight fluorescent green with fluorescent penetrants, it is almost certainly due to insufficient cleaning. Providing good contrast between the background and the smallest defect being sought exists, then the condition is usually acceptable, otherwise stop the test, re-clean thoroughly and begin again.

Some test materials, including stainless steel, have surfaces which are, to a small degree, permeable to penetrants and require special attention when cleaning; however, they will often retain a slight discolouration.

Development times of typically 10 minutes to 30 minutes should be allowed prior to final viewing.

1.4.6 Inspection and interpretation of defects

If all stages of the penetrant process have been applied correctly the position of defects will be indicated as red marks on a white background or as green-yellow marks against a deep violet background if fluorescent penetrants are used.

The larger defects hold a greater volume of penetrant and will therefore be revealed almost immediately, but additional time will be required for tight defects to show.

By noting and comparing the indications that appear during the first 30 seconds with those that exist after say 15 minutes, a more accurate assessment of the defect characteristics becomes possible.

The rate of staining is an indication of the width and depth of the defect whilst the extent of staining is an indication of its volume.

1.4.7 Viewing conditions

Inspection should always take place with good intensity white light if a colour contrast penetrant has been used, or in a darkened area if fluorescent penetrant has been used.

The UV-A (black) light used for the inspection of fluorescent penetrants should have a wavelength between 320 nm and 400 nm. 365 nm gives optimum fluorescence.

The BS 6443 requirements for fluorescent penetrants state that the UV-A irradiance level at the surface being inspected shall not be less than 0.5 mW/cm^2 or $500 \mu\text{W/cm}^2$. For colour contrast penetrants the area under inspection may be illuminated by artificial white light or daylight but should not be less than 500 lux.

1.4.7.1 Reporting

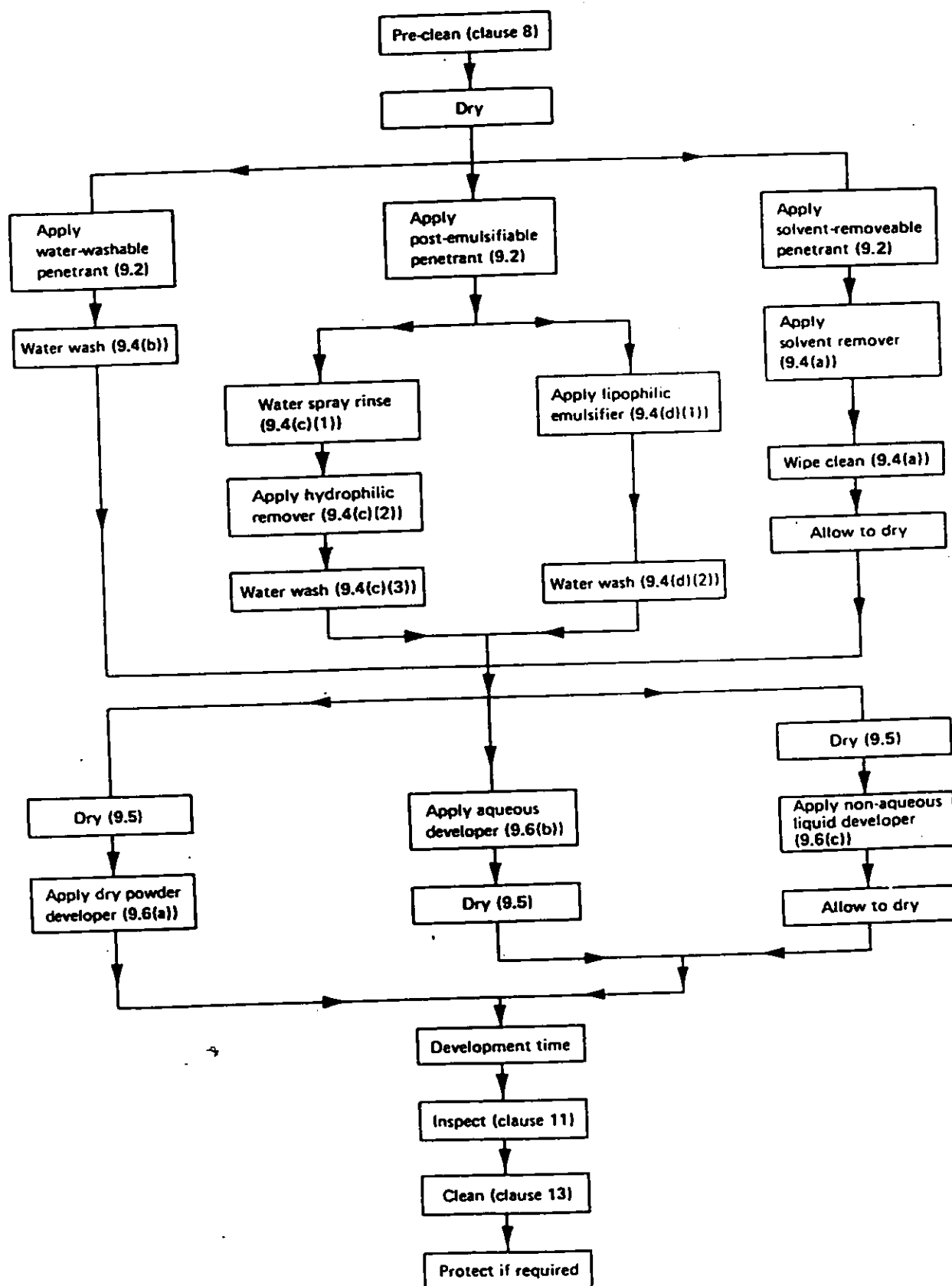
Good reporting is essential if the test results are to be accurately assessed. Details which require reporting should be identified in the test procedure for the work being performed, but typically include the following:

- a. Job identification and identity of test item(s).
- b. Date of test.
- c. Identity and signature of test operatives.
- d. Surface condition - if machined it may be reported as "machined". If welded, state "as welded". There is not normally a requirement to emphasize the surface condition in great detail.

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- e. The process used - it may only be a requirement to refer to the test procedure applicable, the specific details regarding the process being record there. In the absence of a written test procedure a detailed report will be required.
- f. Consumables used - include trade name/identification and batch number of each consumable.
- g. Results and action taken.

1.4.7.2 Sequence of penetrant testing operations
The following table has been taken from *BS 6443*:



LEVEL 2 - PENETRANT TESTING - GENERAL

PAPER No. PT1G2

NAME:

COMPANY:

DATE:

SIGNED:

RESULTS:

1. What is the *flash point* of a solvent based product?
 - A. The minimum temperature at which the solvent will be flammable.
 - B. The temperature at which the vapours given off will spontaneously ignite.
 - C. The minimum temperature at which the vapours given off will ignite if source of ignition is introduced.
 - D. The temperature at which the dye in a solvent based penetrant losses its capillary action.
2. What primarily governs the rate (speed) of a penetrant entering a surface breaking discontinuity?
 - A. Viscosity.
 - B. Capillary action.
 - C. Wetting ability.
 - D. How the penetrant was applied.
3. Aluminium alloy test specimens that have been tested with penetrant should be thoroughly cleaned after testing because:
 - A. the remaining toxic residue from the test may react with the aluminium causing a fire hazard.
 - B. the acid in the penetrant may cause severe corrosion.
 - C. any remaining alkaline penetrant will leave a red permanent stain on the surface of the aluminium.
 - D. the alkaline content of wet and most emulsifiers could lead to surface pitting, especially in high humidity environments.
4. Which penetrant type does not exist?
 - A. Post-emulsifiable fluorescent.
 - B. Post-emulsifiable visible.
 - C. Dual sensitivity penetrant.
 - D. Dry particulate.

5. Why is it bad practice to prepare soft alloy surfaces with a wire brush prior to testing with a penetrant test method?

- A. It may cause damage to the part.
- B. It may close any surface breaking discontinuities.
- C. It is not considered bad practice.
- D. Both A and B are correct.

6. Which of the following NDT methods is most likely to detect fatigue cracks?

- A. Penetrant testing.
- B. Radiographic testing.
- C. MPI.
- D. Ultrasonic testing.
- E. It depends on many factors, none of the above may be selected due to lack of information.

7. Which of the following pre-cleaning methods is generally considered unsuitable for penetrant testing without further processing?

- A. Vapour degreasing.
- B. Abrasive blasting.
- C. Solvent cleaning.
- D. Steam cleaning.

8. Capillary pressure is influenced by which of the following penetrant properties?

- A. Surface tension.
- B. Wetting ability.
- C. Dimensions of surface breaking flaw.
- D. All of the above.
- E. A and B only.

9. Of the following, which is the most important reason for filtering the ultraviolet light used for fluorescent penetrant inspection?

- A. To minimize the total light intensity by filtering out the visible light rays.
- B. To produce better viewing conditions in darkened areas.
- C. To reduce the overall wavelength band to allow only green fluorescence.
- D. To prevent personal injury from the more penetrating ultraviolet rays.

10. How would an ideal emulsification time be established when using post-emulsifiable penetrants?

- A. By calculation.
- B. By experimentation.
- C. By measuring the contact angle of the penetrant.
- D. By determining emulsifier viscosity.

11. Generally speaking, which of the following penetrant systems would be the most time consuming to use on the same type of component?

- A. Solvent based.
- B. Post-emulsifiable.
- C. Water-washable.
- D. All of the above would take the same time.

12. Which of the following statements is true?

- A. Lipophilic penetrant systems always require the use of a water wash immediately prior to the application of an emulsifier.
- B. Hydrophilic penetrant systems always require the use of a water wash immediately prior to the application of an emulsifier.
- C. Lipophilic penetrant systems may or may not require the use of a water wash immediately prior to the application of an emulsifier, depending on the specification or procedure requirements for the contract.
- D. Hydrophilic penetrant systems may or may not require the use of a water wash immediately prior to the application of an emulsifier, depending on the specification or procedure requirements for the contract.

13. Which of the following may be used to apply penetrant effectively?

- A. Spray.
- B. Immersion.
- C. Electrostatic spray.
- D. Brush.
- E. All of the above.

14. Which of the following is not considered good practice when penetrant testing?

- A. Applying emulsifier by dipping the part in emulsifier.
- B. Applying developer by dipping the part in developer.
- C. Removal of water-washable penetrant with a water spray.
- D. Applying emulsifier with a brush.

15. Dry developer should be applied:

- A. so that a heavy coat of developer covers all surface to be inspected.
- B. so that a light dusting covers all surfaces to be inspected.
- C. with a dry soft brush, e.g. paint brush.
- D. by dipping.

16. The profile of the meniscus of a penetrant would be:

- A. concave when compared to the meniscus of a penetrant with lower penetration properties.
- B. convex when compared to the meniscus of a penetrant with lower penetration properties.
- C. flat.
- D. All the above may be true for a penetrant.

17. Why is it advisable to have a UV-A light installed at the wash station when using fluorescent penetrant systems?
- A. So that the drying stage may be eliminated.
 - B. To increase the *bleed out* speed of the penetrant.
 - C. To check the effectiveness of the wash cycle.
 - D. To determine if the parts have been adequately covered with penetrant.
18. Which factor would apply for determining the penetrant contact time required for the test method to be effective?
- A. Type of discontinuity sought.
 - B. Shape of the component.
 - C. Size of the component.
 - D. All of the above.
19. Why is the wetting ability a consideration in the design of penetrants?
- A. Because it has an effect on capillary action.
 - B. Because it has an effect on the penetrant's coverage of a component's surface.
 - C. Both A and B are correct.
 - D. Wetting ability is not a consideration in the design of penetrants.
20. Why are visible penetrants usually red?
- A. Red provides high definition.
 - B. Red dyes are cheaper than others.
 - C. Red provides a high contrast against a white background.
 - D. Convenience.
21. Which of the following statements is false?
- A. Penetrant testing can find most types of surface breaking discontinuity, although it cannot accurately size all discontinuities.
 - B. Penetrant testing, in most circumstances, can be just as reliable as MPI for detecting surface breaking defects in ferromagnetic materials.
 - C. Penetrant testing may detect fatigue cracks.
 - D. The penetrant test method is less reliable than radiographic testing when attempting to detect minute surface breaking discontinuities.
22. Which of the following would be the most desirable centre wavelength for the light used in the fluorescent penetrant process?
- A. 3200Å (320nm). nm
 - B. 3650Å (365nm). nm
 - C. 4650Å (465nm). nm
 - D. 5960Å (596nm). nm
23. A good commercial penetrant should have a:
- A. low flash point.
 - B. high flash point.
 - C. flash point lower than 55°C.
 - D. Flash point is not relevant.

24. Which of the following materials is often difficult to test with a penetrant test method, due to lack of contrast during final interpretation?
- A. Ferromagnetic C-Mn steel.
 - B. Aluminium.
 - C. Titanium alloys.
 - D. Cast iron.
25. If a penetrant system is *halogen free* it will contain no:
- A. sulphur.
 - B. dye.
 - C. chlorine.
 - D. solvent.
26. Which of the following statements is false regarding the use of cracked panels or *comparator blocks*?
- A. To establish a standard size of crack which can be reproduced as needed.
 - B. To determine the relative sensitivities of two penetrants.
 - C. To determine if a fluorescent penetrant has lost or reduced its fluorescence.
 - D. To determine the degree or method of cleaning necessary to remove penetrant from the surface without removing it from the cracks.
27. Which of the following penetrant test methods is the most common found on *site work* if used on ferromagnetic pipework or pressure vessels?
- A. Water-washable (visible).
 - B. Post-emulsifiable (fluorescent).
 - C. Solvent based (fluorescent).
 - D. Non-aqueous (visible).
28. When using fluorescent water-washable penetrants, adequate rinsing time is assured by:
- A. timing the rinse cycle.
 - B. scrubbing the part surface.
 - C. rinsing under UV-A light.
 - D. using a high pressure water blast.
29. How long must a penetrant be left on a part before the removal stage is started?
- A. As long as possible.
 - B. 20 minutes.
 - C. It varies depending on the type of penetrant used, the type of material being tested, the sensitivity desired and the type of discontinuities to be detected.
 - D. It varies depending on the type of material being tested, the sensitivity desired and the size of discontinuities to be detected, but will not exceed 20 minutes.

30. You (as a fully qualified level II penetrant tester) have been requested by telephone to carry out penetrant testing on a steel structure to locate any fatigue cracks which may exist, the client is out of the country and the job is urgent. The structure consists of plates and tube attached by fillet welds and has a total surface area of 40m². You have arrived at the fabrication shop where the structure is waiting to be tested and you only have the above verbal instructions. What would be the best approach.

- A. Test the component over the entire accessible surface area and report on any defects found on the plates, tube and/or welds. Request repairs, cut-outs, or any other action which you consider necessary to take if defects exist.
- B. Test the component over the entire accessible surface area and report on any defects found on the plates, tube and/or welds. Do not request repairs, cut-outs or any other action which you consider necessary to take if defects exist, although an opinion may be given.
- C. Test the fillet welds only and report on any defects found. Request repairs, cut-outs or any other action which you consider necessary to take if defects exist.
- D. Only test the fillet welds and any other areas consisting of a sharp change in contour and report on any defects found. Do not request repairs, cut-outs or any other action which you consider necessary to take if defects exist, although an opinion may be given.

The first part of the paper discusses the importance of understanding the cultural context of the research. It highlights the need for researchers to be sensitive to the values and beliefs of the communities they are studying. This is particularly important in the field of education, where cultural differences can significantly impact learning outcomes.

The second part of the paper focuses on the methodology used in the study. It describes the process of selecting participants, collecting data, and analyzing the results. The authors emphasize the importance of using a mixed-methods approach, which combines both qualitative and quantitative data to provide a more comprehensive understanding of the research topic.

The third part of the paper presents the findings of the study. It discusses the results of the data analysis and how they relate to the research objectives. The authors note that the findings suggest that there are significant differences in learning outcomes between different cultural groups, and that these differences can be attributed to a variety of factors, including language barriers and cultural differences in learning styles.

The final part of the paper discusses the implications of the findings for future research and practice. It suggests that researchers should continue to explore the cultural context of education and develop strategies to address the challenges faced by different cultural groups. The authors also recommend that educators should be trained to be culturally sensitive and to use a variety of teaching methods to meet the needs of all students.

**MAGNETIC PARTICLE
INSPECTION**

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NOTES

Ferromagnetic materials are those which may be magnetized, e.g. iron, cobalt nickel and many of their alloys.

The area being tested is known as the "test area".

Magnetic particle inspection (MPI) is an NDT method which may only be used on ferromagnetic materials to detect surface breaking discontinuities and also, in certain cases, slight sub-surface discontinuities up to 2 mm or 3 mm below the material's surface.

Basic principles

A magnetic field is introduced into a specimen to be tested, then fine particles of ferromagnetic powder, or ferromagnetic particles in a liquid suspension, are applied to the area being tested. Any discontinuity in the test area which cuts across the magnetic field creates a *leakage field*. A leakage field has a north and south pole on either side of it, and therefore will attract the ferromagnetic particles in great numbers.

It is common on site work to use *black inks* as the detecting medium; these are usually contrasted against a white paint background which has been pre-applied. In workshops and similar, it is more common to use *fluorescent inks* which are usually green/yellow. Fluorescent inks or powders are automatically contrasted against a deep violet background created by the use of an ultraviolet (UV-A) light, this is essential to cause fluorescence of the particles, although the use of a darkened inspection area is required. A contrast paint is not required with fluorescent inks.

Fluorescent inks or powders are more sensitive at detecting defects compared to non-fluorescent inks or powders, because of the greater contrast achieved between the detecting medium and the background.

There are many ways to apply a magnetic field, e.g. by the use of permanent magnets, electromagnetic yokes, coils, prods, cables and other devices.

A basic sequence of operations for the examination of a weld using MPI with a permanent magnet and black ink is shown below:

1. Clean area using a wire brush if required.
2. Apply a thin layer of white contrast paint.
3. When the paint is dry, straddle the magnet over the weld at 90° to the welds axis.
4. Apply ink (1.25% to 3.5% ferromagnetic particles to a paraffin base).
5. Interpret the area. Look for indications with their length lying along the same axis as the weld. Evaluate in accordance with the relevant specification.
6. To look for transverse weld defects, turn magnet approximately 90° and re-apply the ink.
7. Interpret the area. Look for indications with their length perpendicular to the weld axis. Evaluate in accordance with the relevant specification.

NOTES

Magnetism

All materials consist of atoms and molecules which may or may not have a permanent magnetic influence depending on the electron configuration within the material.

Atoms in magnetic materials group together in regions called magnetic domains; each domain has its own north and south pole. When these domains are randomly positioned, the material is unmagnetized. If the domains are aligned in a common direction, then the material will be magnetized and the material itself will have its own north and south pole.

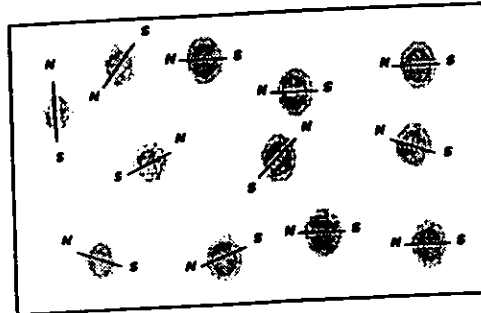


Fig. 2.1. Position of domains in unmagnetized material.

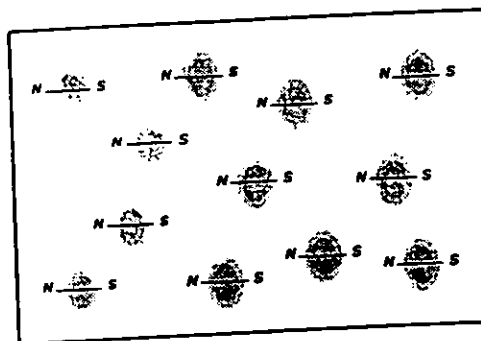


Fig. 2.2. Position of domains in magnetized material.

The domains can be aligned by bringing them within an existing magnetic field. If the domains remain aligned when they are removed from the influence of the magnetic field, then the material is said to be permanently magnetized.

The poles of magnetized materials have an inherent attraction/repulsion effect. If two pieces of magnetized material are placed with their dissimilar poles end to end there is an attraction, but if the poles are alike then there is repulsion, therefore:

like poles repel, unlike poles attract.

Lines of force

Faraday used the concept of lines of force to explain what happens in the space between two magnets. He suggested properties for these lines of force, which he imagined as spreading out from all magnetic poles into the surrounding space.

The symbol Φ (Phi) is used to represent magnetic lines of force. Magnetic lines of force may also be termed magnetic flux.

NOTES

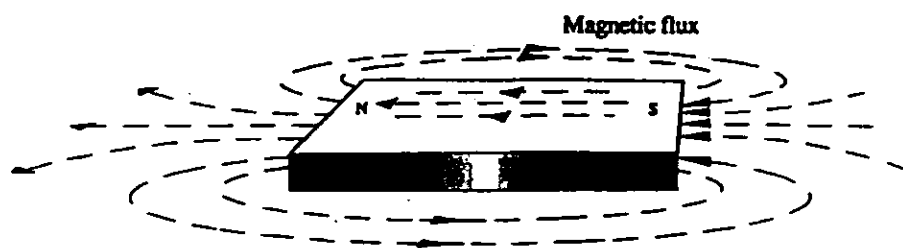


Fig. 2.3. Lines of force around a bar magnet.

By assuming the lines were in tension, like pieces of stretched elastic, he could account for the attraction of unlike poles, since the lines of force stretch from one pole to another.

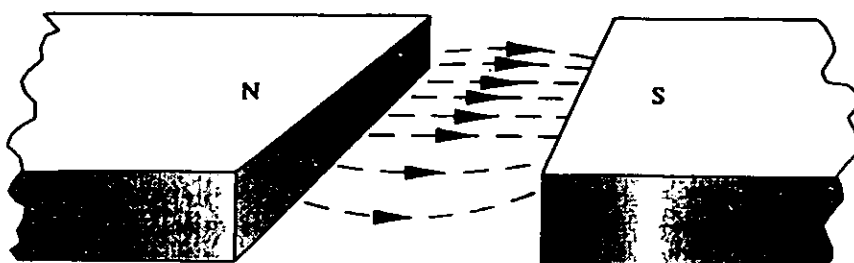


Fig. 2.4. Lines of force for unlike poles.

But, the tension of the lines of force must increase as they shorten, since the repulsive force between two like poles increases as the poles approach. With like poles, the lines of force also tend to curve outwards, seeming to suggest that they repel each other. Faraday used this hypothesis to account for the repulsion of like poles.

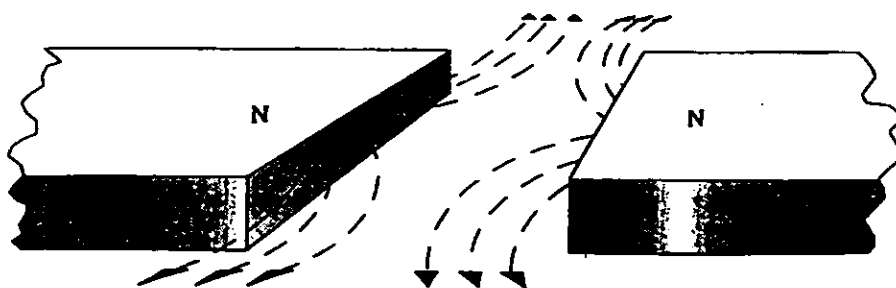


Fig. 2.5. Lines of force for like poles.

The properties of magnetic lines of force are as follows:

- a. They form closed loops between north and south poles.
- b. They do not cross one another.
- c. They seek paths of least magnetic resistance.
- d. Their density decreases with increasing distance from the poles, i.e. the number of lines of force in a unit area decreases.
- e. They are considered to have direction, that is: from the north pole to south pole external to the magnet, and from the south pole to the north pole within the magnet.

NOTES

Material characteristics

The degree to which materials are capable of being influenced by a magnetic field varies greatly from material to material, however they fall into three specific categories defined by their behaviour in the magnetic field.

Diamagnetic materials

These are, to a very slight degree, repelled by a magnetic field and include copper, aluminium, titanium and most non-metals.

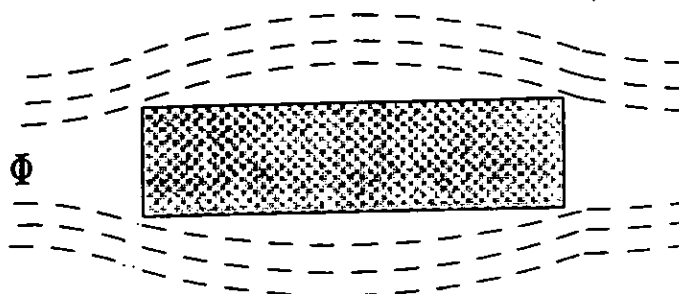


Fig. 2.6. Lines of force for a diamagnetic material.

Paramagnetic materials

These are very weakly attracted by a magnetic field and include oxygen and most metals.

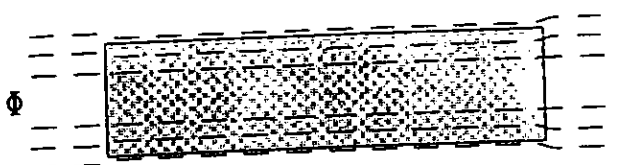


Fig. 2.7. Lines of force for a paramagnetic material.

Ferromagnetic materials

These are strongly attracted by a magnetic field and include iron, cobalt, nickel and many of their alloys. They also exhibit permanent magnetism and can themselves be magnetized.

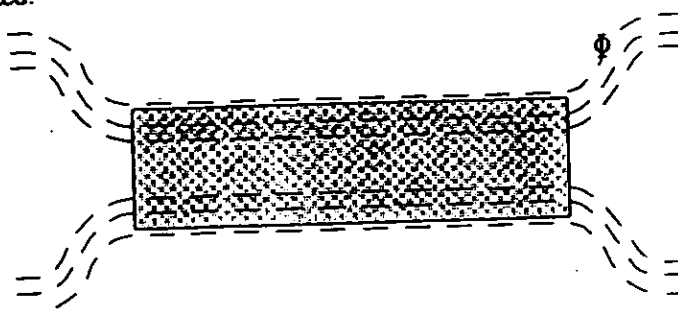


Fig. 2.8. Lines of force for a ferromagnetic material.

NOTES

Permeability (μ)

For magnetic particle inspection, the only materials of interest are those which are ferromagnetic. Within this group, some materials are more easily magnetized than others, that is to say more permeable.

To permeate means to spread through. In this context it refers to the ease by which the magnetic lines of force are spread through the material. Soft iron and low carbon steel have a high permeability, i.e. they are easy to magnetise. Hard iron and high carbon steel have a low permeability, i.e. they are difficult to magnetise.

Permeability (μ) may be calculated by dividing the magnetic force (H) applied, into the flux density (B) achieved:

$$\mu = \frac{B}{H}$$

The permeability of a material may be given a value based on a ratio when compared with free space. These values vary depending on alloy composition, heat treatment and any working applied.

Magnetic force (H) may also be termed "magnetic field strength".

Flux density (B) may also be termed "magnetic induction".

Retentivity

When a magnetizing force is removed from a ferromagnetic material the amount of magnetism remaining will vary between materials and depends upon the permeability of the material. The remaining magnetism is termed *residual magnetism* and the material is said to have *retentivity* or *retained magnetism*.

If a material has high permeability it is easily magnetized, but it will just as easily give up the magnetic force, therefore it has a low retentivity.

If a material has low permeability it is very difficult to magnetise, that is to say it has high magnetic reluctance, but once magnetization has been achieved then it does not give up the magnetic force easily, therefore it has high retentivity.

High permeability = low retentivity

Low permeability = high retentivity

Magnetic flux (Φ) and magnetic flux density (B)

When a specimen is magnetized, lines of force or flux exist within the specimen - the stronger the magnetizing force applied, the greater the amount of flux produced. The magnetizing force may be applied by using a permanent magnet or electrically operated magnetic flow apparatus, or by passing an electric current through the specimen.

Magnetic flux is measured in webers (Wb).

The number of lines of force (or flux) passing transversely through a given cross-sectional area is known as the flux density (B). Flux density is measured in tesla (T). $1 \text{ Wb/m}^2 = 1 \text{ tesla (T)}$.

The old (cgs) unit for flux density which is still widely encountered is the gauss:

1 gauss = 1 line of force/cm².

10,000 (10⁴) gauss = 1 tesla.

BS 6072 - Magnetic particle flaw detection, states that MPI shall only be carried out if the magnetic flux density level at the surface of the test area is equal to, or greater than, 0.72T. This level of flux density is approximately one-third of that required to magnetically saturate most steels.

NOTES

Magnetic field strength (H)

The magnetic field strength or magnetizing force is that which is needed to induce a flux in a magnetic circuit and is measured in amperes per metre (A/m), or in old (cgs) units, the oersted (Oe).

1 oersted = 79.58 amperes per metre

Coercive force

Coerce means to forcibly control; in this context it relates to the reverse magnetizing force necessary to remove remnant or residual magnetism for demagnetization of a part.

Magnetic hysteresis

Most of the magnetic properties of materials of practical concern in MPI are defined by the magnetic hysteresis loop or B&H curve.

When an unmagnetized piece of ferromagnetic material is exposed to a gradually increasing positive magnetic force, and the strength of the induced flux density (B) is plotted against the magnetizing force (H), a B&H curve is produced. If the plot continues in the opposite direction a hysteresis loop evolves.

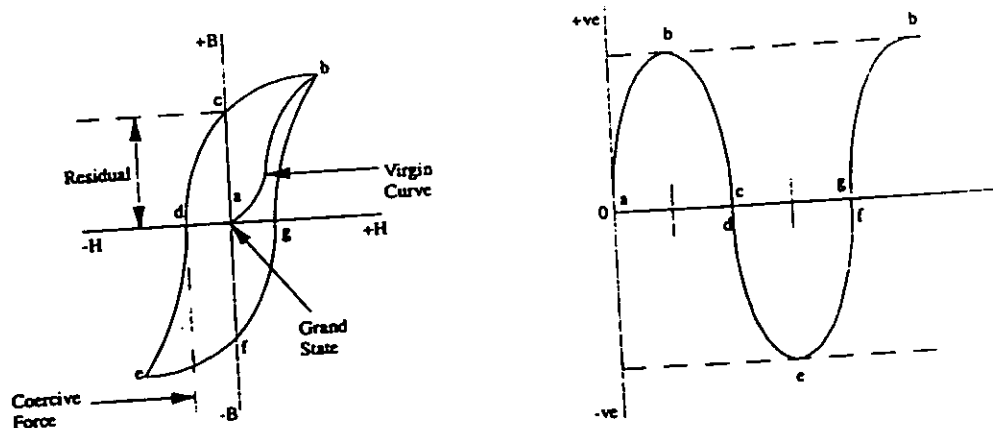


Fig. 2.9. A typical hysteresis loop generated by an a.c. current.

As the magnetizing force (H) is increased, the induced magnetic field (B) also increases until it reaches its saturation point (b), at this point the material is said to be magnetically saturated, that is the point when the maximum flux density has been reached.

When the magnetic force (H) is reduced, the flux density (B) also reduces, but falls behind the original curve so that when H is back to zero there is still some magnetic flux in the material (c). This is a measure of the materials retentivity.

If the polarity of the magnetizing force is now reversed, B will return to zero (d). This point represents the coercive force required to remove the residual magnetism from the material.

NOTES

By continuing all the previous actions in the opposite direction a complete loop will be formed.

When a.c. is used for magnetizing a specimen, a complete hysteresis loop is produced with each cycle of current; in the U.K. this is 50 times per second.

A material which exhibits a hysteresis loop with a wide appearance will have high retentivity and therefore may be useful for making permanent magnets. A material which exhibits a hysteresis loop with a narrow appearance will have low retentivity and therefore may be useful for making magnetic particles.

The gradient of the loop also gives information regarding on the usefulness of materials for use in magnetising apparatus, for making magnetic particles or for magnetising purposes. For example, a material which exhibits a steep gradient will attain a high flux density when using a low magnetizing force.

Penetration of magnetic flux

Magnetic particle inspection is primarily used for the detection of surface breaking discontinuities and only in ferromagnetic materials. This is because the magnetic fields induced are concentrated at the surface of the components. However, sub-surface discontinuities may be detected if using permanent magnets or electrical systems using direct or rectified current, because the magnetic field penetrates much further into the test specimen in comparison with MPI test methods which use alternating current. It is unlikely that any form of MPI would be used to detect defects deeper than 2 mm or 3 mm below the surface.

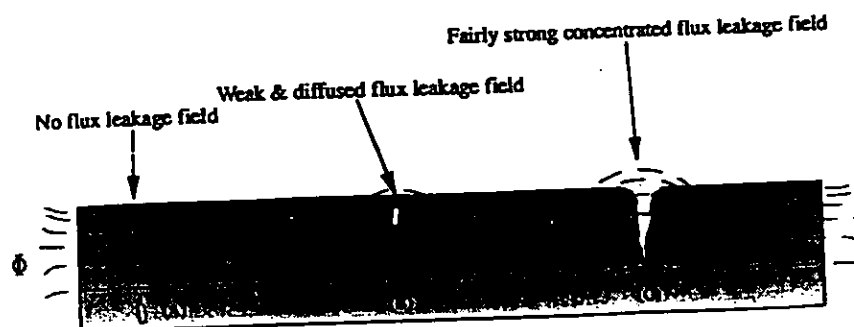


Fig. 2.10. Flux leakages around discontinuities at different depths using a standard permanent magnet used in MPI. (A) will not be detected, (B) may be detected if the appropriate technique is used and (C) should easily be detected.

MPI test equipment using alternating current as an output produces a high density magnetic flux at the surface of the test component. This phenomena, known as the *skin effect*, produces a far stronger flux leakage field on surface breaking, or near surface discontinuities, compared to permanent magnets or direct current test equipment.

The depth of flux penetration is governed by the wave frequency of the alternating current, the conductivity of the test material and its permeability. If any of these variables increase, the depth of penetration will decrease.

It is difficult to try and interpret very weak and diffused MPI indications which could be from sources other than defects, e.g. caused by rough/uneven surfaces or changes in permeability. Because of this problem, sub-surface, or body defects, would normally

NOTES

be located by other methods of NDT, assuming the detection of sub-surface defects is a requirement.

Flux leakage

When a magnetic field is created within a ferromagnetic specimen, lines of magnetic flux are developed and flow through and around the material completing a circuit. Magnetic particle inspection relies on a leakage of flux occurring within this circuit, this may be caused by a break or discontinuity in the material.

Because it is a change in magnetic permeability that causes a leakage field, flux leakages may also be caused by changes in metallurgy.

Opposite poles attract, therefore any break or discontinuity causing a flux leakage will, because of the magnetic poles, attract a ferromagnetic material such as iron powder. This would accumulate at the area of the leakage field and give an indication of the defects existence.

Where the flux leaves the circuit a north pole is created.

Where the flux re-enters the circuit a south pole is created.

For a defect to be detected by MPI it must interrupt the lines of force. Any linear defects running parallel with the flux or small non-linear defects do not break the lines of force, they bend around these defects taking the path of least resistance; these defects therefore remains undetected.

MPI is most effective in detecting defects with their major axis at 90° to the lines of force, but will usually remain effective down to about 45° of this axis. Below this it is unlikely that the defect will be found, therefore in order to examine a specimen completely, the lines of force must be applied in different directions.

Electromagnetism

There is a fundamental relationship between electricity and magnetism; the movement of an electric charge will create a magnetic force field around it, in a plane perpendicular to the direction of travel of the electric charge.

Electrons that are moving in a current carrying conductor set up a magnetic field, the direction and orientation of which are given by the right hand rule if we assume the current flow, by convention, is opposite to electron flow; or the left hand rule if we assume the direction of current flow is the same direction as the electron flow.

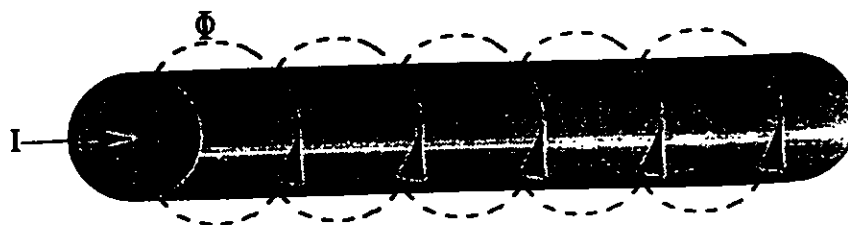


Fig. 2.11. Magnetic lines of force in relation to current flow (I) using the left hand rule. The symbol I is used to indicate the current flow, Φ symbolises magnetic flux flow.

It is a change in magnetic permeability that causes a leakage field.

Cracks may have very irregular contours, they therefore may sometimes be detected using MPI when the lines of force are parallel, or close to parallel, to the cracks major axis.

A sharp change in contour can also create a flux leakage creating an MPI indication known as "furring". Furring can also occur on flat surfaces when there is an excessive amount of magnetic flux.

NOTES

1. Magnetic particle flaw detection is capable of detecting cracks, non-metallic inclusions and other discontinuities on or near the surface of ferromagnetic materials.
2. The sensitivity of the inspection is not greatly impaired by the presence of foreign matter within the flaws, unless the contaminate has magnetic properties similar to the test piece (which is highly unlikely).
3. It is possible to inspect components that have been coated, e.g. with cadmium plate or paint, providing the coating is not too thick (usually not greater than 50 µm) with only a slight loss of sensitivity.

Limitations of MPI

1. MPI cannot be used on non-magnetic material.
2. The presence of surface coatings may reduce the sensitivity of the test.
3. Flaws that do not break the surface give diffused indications; these indications from flaws become increasingly diffused with an increase in distance below the surface.
4. Dimensional and/or structural variations, rough surfaces, and certain types of segregation or metallurgical changes associated with test items may give rise to misleading indications.

General considerations:

1. All persons associated with magnetic flaw detection should be adequately trained to an agreed level appropriate to their responsibility and have adequate eyesight. BS 6072 states that persons carrying out MPI should be able to read the Jaeger J2 chart at a distance of 0.5 metres.
2. It is necessary for operators and supervisors to observe the requirements of the Health and Safety at Work etc. Act 1974 and the COSHH Regulations; see Unit MT12.
3. Post cleaning may be necessary in circumstances where the magnetic particles or any background paint used, may be deleterious to the successful use of the component.

Surface conditions

The better the surface condition, the more sensitive and reliable the test will be. Therefore all contaminants such as paint, dirt, grease, oil, scale etc. should be removed, leaving if possible a smooth surface dressed to bright metal.

Where dressing is not possible and when black inks are being used, a coating of a suitable white background contrast paint should be applied.

Contrast paints should normally be in accordance with BS 5044 - *Contrast paints used in magnetic particle flaw detection*.

Contrast paint should be applied thinly. Thick coats reduce the sensitivity of the process and take longer to dry.

Contrast paints are usually water based nowadays and therefore not as toxic as those containing volatile solvents.

NOTES

Permanent magnets

Permanent magnets are so called because they are able to maintain a magnetic field in the surrounding space. The field strength can vary considerably, depending on the flux density in the magnet and its shape.

The simplest form of permanent magnet is a bar magnet, which is basically a piece of ferromagnetic material with a magnetic pole at each end.

If the bar was formed into a closed loop, then the magnetic field would be fully contained within a closed circuit and no external field would exist. If a defect was present in the loop, a flux leakage would still occur.

Neither bar magnets or ring (looped) magnets have any use in MPI. But, if a bar magnet is simply formed into a U shape, the magnetic lines of force will be concentrated in the gap between the magnetic poles; this provides an ideal configuration for magnetic particle inspection.

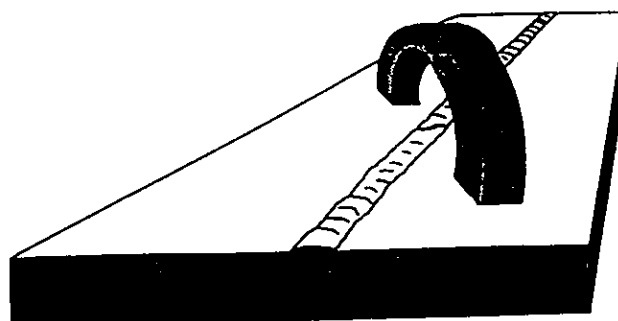
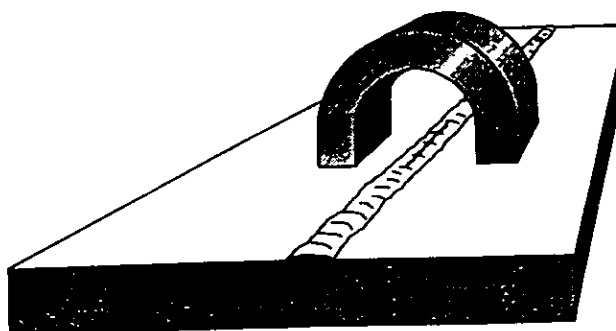


Fig. 4.1. Permanent magnets positioned for examining a weld.

Permanent magnets provide magnetic flow only in the specimen and produce a longitudinal magnetic field between the poles.

The degree of magnetization in permanent magnets is determined by the amount of *pull* required to lift the magnet clear of the workpiece, or by its *lifting power*.

The *pull off force* is the force that has to be applied to one pole to break its attraction to the surface, whilst leaving the other pole attracted.

The *lifting power* is the ability of the magnet to lift a piece of ferromagnetic material by attraction alone.

NOTES

Certain specifications will state the minimum requirements for the strengths of permanent magnets, e.g. BS 6072 states that permanent magnets shall have a power capable of lifting 18 kg with a pole spacing 75-150 mm. The pull off force shall have a value equivalent to at least 9 kg.

When not in use a permanent magnet should have a *keeper* placed across the poles to prevent loss of magnetism.

Some permanent magnets may have adjustable arms, others may have rollers attached to the poles; the rollers are set to keep the magnet just clear of the surface and enable it to be moved over the workpiece with relative ease.

Advantages of permanent magnets include:

- No power supply required.
- Inexpensive.
- No damage to the test piece from arcing.
- Relatively lightweight (easily portable).
- They cling to vertical and overhead surfaces.
- Both hands free after the magnet is placed onto the surface.

Disadvantages include:

- Deterioration with wear.
- Have to be pulled from the test surface.
- Magnetic particles attracted to poles.
- Limited application on awkward shapes.
- No control over field strength (unless adjustable arms are used).
- Only small areas examined in each position.

Electromagnetic yokes

Electromagnetic yokes or *electromagnets* require a source of electrical energy which may be a.c. or d.c.. The test method used is sometimes referred to as the *magnetic flow* or magnetic flux path method.

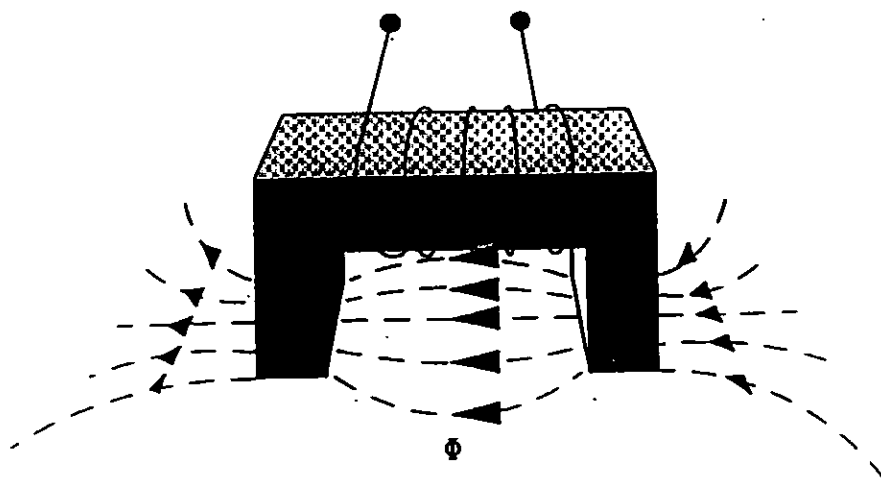


Fig. 4.2. An electromagnetic yoke.

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The yoke is made from highly permeable, low retentive steel, which is laminated to reduce induction caused by eddy current flow (associated only with alternating current) and also helps to prevent the yoke becoming permanently magnetized.

Magnetism is induced into the yoke by encircling it with a coil through which a current is passed, the strength of the field produced can be varied in one of two ways:

1. By adjusting the current (amperage) flowing through the yoke - only certain electromagnets allow for this.
2. By varying the distance between the pole pieces - most electromagnets allow for this but not all.

Electromagnets may operate direct from the mains supply of 240V but are available at 110V when required for site use.

The field produced in electromagnetic yoke is longitudinal, travelling from pole to pole as with permanent magnets, however the depth of the field within the test piece will depend upon the type of current used to induce magnetism.

Surface discontinuities will be more readily found using a.c., sub-surface defects will be more easily located using d.c.. The magnet will have a much greater pull on d.c. but the flux will be less at the surface of the component being tested.

BS 6072 states that a.c. electromagnets should have a lifting power of at least 4.5 kg for a pole spacing of 300 mm or less, the standard also gives a minimum pull-off rating of 2.25 kg for the same pole spacing. For d.c. electromagnets, the lifting power and pull-off rating is the same as for permanent magnets.

Advantages of electromagnetic yokes include:

- A.c. or rectified d.c. operation.
- Controllable field strength (not in all cases).
- Can be switched on/off as required.
- No damage done to test piece.
- Relatively lightweight.
- A.c. yokes can be used to demagnetise.

Disadvantages include:

- Power supply required.
- Only small areas can be examined at each magnet location.
- Leaves only one hand free.

NOTES

Current flow

Current flow techniques produce a circular magnetic field by passing a current through the test piece, i.e. concentric rings of magnetic lines of force radiate at 90° to the current flow.

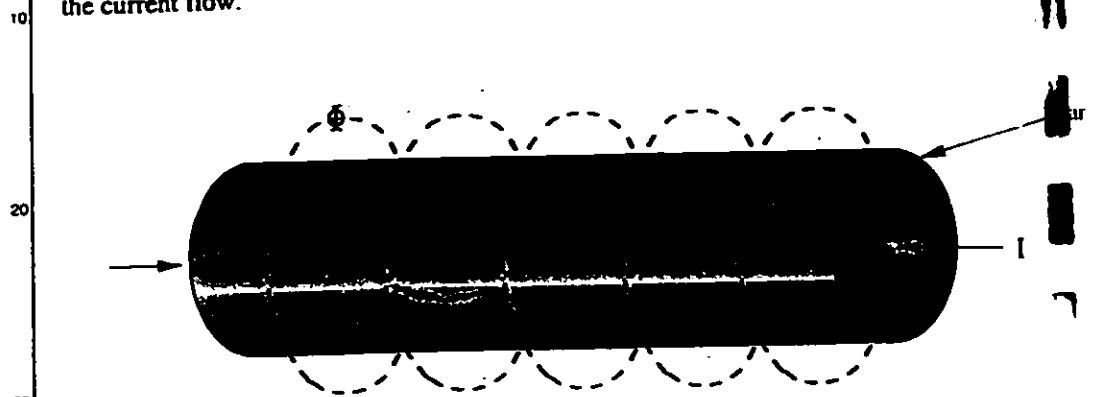


Fig. 4.3 Current flow method on bar.

The current flow is normally obtained from a transformer supplying a.c. or a transformer rectifier for d.c..

The output voltage of current flow equipment is so low that there is no risk of electrical shock to the operator from the equipment's specimen contact points or test specimen.

The choice of power supply depends on the test requirements, i.e. using a.c. will reveal flaws up to approximately 1 mm below the surface, using d.c. will reveal defects typically up to 2 mm to 3 mm below the surface.

An ammeter is usually incorporated in the equipment to indicate the amount of current flowing through the workpiece.

In fixed installations, i.e. bench equipment, the component is firmly clamped between contact heads. With portable equipment, electrical contact is made by the use of prods and/or clamps.

Prod technique

With this technique the current is introduced into the item under test by using electrical contacts known as *prods*. Prods induce a circular magnetic field within the specimen using current values typically in the region of 1000 amps; at this current level arcing can occur between the electrodes and the test surface causing damage. To prevent this possible damage, the prod contact tips and the test surface must be kept clear of any contamination and the current must not be switched on until firm contact has been established, likewise, the current should be switched off before lifting the prods.

Because of the risk of arc strikes many specifications do not allow the use of the prod technique.

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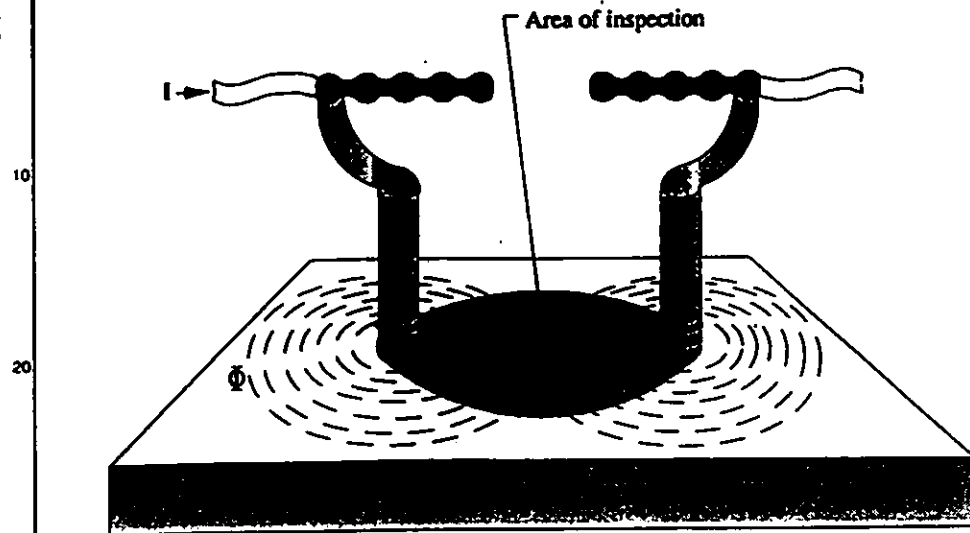


Fig. 4.4. Current flow using prods..

Precautions when using current flow in respect to prods/clamps are given in BS 6072:

'Every precaution shall be taken to prevent excessive heating, burning or arcing. Certain metals including copper and zinc may, if used as prod material, contaminate and cause metallurgical damage to the component if arcing occurs. For this reason and the fact that perfect contact is difficult to achieve with prods, they shall be made of steel or aluminium. Zinc shall not be used and copper or copper-tipped prods shall be used only in applications where complete assurance can be given that metallurgical damage will not occur. The cleanliness of both prod contact faces and the component shall be such to ensure good electrical contact. Prods shall have a minimum dimension of 10 mm and shall have as large a contact area as possible. Arcing or excessive heating shall be regarded as a defect requiring a verdict of acceptability. If further testing is required on such affected areas, it shall be carried out using a different technique.

Note: Lead contact pads may be used, but only in well ventiated conditions, because they may generate harmful vapour which may cause headaches and/or dizziness.'

Since the lines of force radiate from the prods, correct positioning is essential to ensure that all possible defects are located. Ideally the prods should be in a line parallel to, and on the same axis, as the defects being sought.

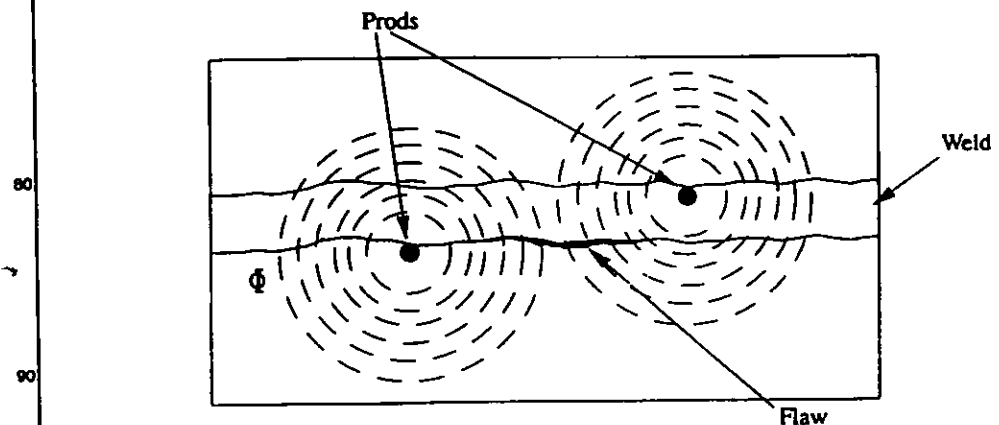


Fig. 4.5. Position of prods should ideally be parallel to defects being sought.

NOTES

Magnetizing methods other than the use of prods may leave residual fields, but generally speaking, these fields are less likely to oppose or destructively interfere with the field introduced by the next magnetizing position.

The BS 6072 specifies the minimum amperage for the prod technique as 7.5 amps peak current value per 1 mm of prod spacing, or 5.3 amps of a.c. r.m.s.; this applies to flat areas and slightly curved surfaces, other values are stated for other shapes.

When using prods the field strength should normally be checked by the use of flux indicators.

Advantages of the prod technique include:

- A.c. or d.c. fields.
- Low voltage output.
- No poles to attract magnetic particles.
- Variable field strength.
- Can be used in confined spaces.
- Relatively fast coverage of area under test.

Disadvantages include:

- Risk of creating arc strikes.
- Heavy transformer required.
- Contacts and small test items can overheat.
- Careful positioning and spacing of prods required.
- Possible to switch on without creating a field.
- May leave residual field which interfere with next prod positions (see side note).

Contact heads

Current flow can also be achieved in regularly shaped items, e.g. bar or tube, applying contacts, usually copper gauze, to the ends of a test piece and passing a high amperage, low voltage current through it. This sets up a circular field in the ferromagnetic material in a direction at 90° to the current flow, therefore the technique is used for detecting defects parallel to, and up to 45°, of the current flow, e.g. longitudinal defects in bar.

Irregular shaped items may also be tested by contact heads, although, depending on the components shape and dimensions, it may be preferable to use an alternative method.

The BS 6072 recommends the use of the following current values:

- For regular objects 5.3 amps a.c. r.m.s. or 7.5 amps d.c. is recommended per 1 mm diameter; all waveforms 7.5 amps peak.
- For irregular, or regular shaped items, using a.c., for every 1 mm of peripheral length $\times 1.7$ amps a.c. r.m.s.

Other factors for different current types are listed in the BS 6072.

Cross sectional variations of 1 : 1.5 or more, will require two or more current values.

NOTE: To enable current (I) to be calculated:

$$\text{Peripheral length} = \pi \times \text{diameter}$$

$$\text{Diameter} = \frac{\text{peripheral length}}{\pi}$$

Induction methods

Induction MPI methods do not necessarily require any contact between the magnetizing apparatus and the test specimen.

NOTES

Threader bar

Sometimes known as the central conductor method, although the conductor need not always be central.

The object being examined must be of hollow section and access must be available to both ends, providing these limitations are met, then a conductor - typically made of brass, copper or aluminium, and carrying a current - is threaded through the bore, or aperture, and a current passed through it.

This sets up a circular field in the surrounding ferromagnetic material in a direction at 90° to the current flow, therefore the technique is used for detecting defects parallel to, and up to 45°, of the current flow, e.g. longitudinal pipe defects.

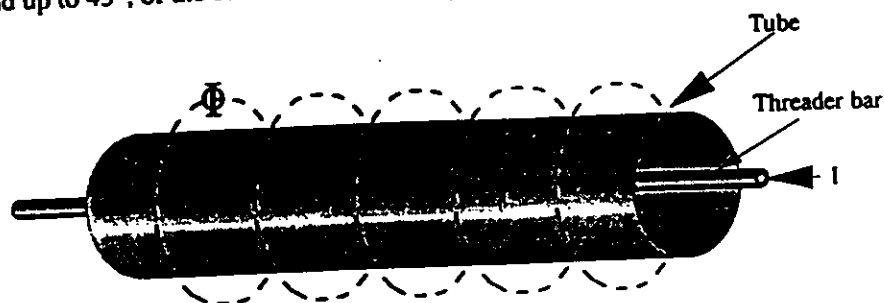


Fig. 4.6. Threader bar method.

The conductor may be located centrally to the specimen, but on larger diameters the conductor is often placed to one side to ensure sufficient flux strength and the test piece rotated to allow for surface inspection. Alternatively, two conductors may be used on larger diameter test pieces.

The threader bar technique is ideal for the testing of ring like specimens, especially because numerous samples may be tested at the same time; lengths of pipe may also be examined by this method. On site work, this technique is not widely encountered, but could be modified by using a flexible cable instead of rigid conductor.

When using a threader bar that is not covered with insulating material, care should be taken to ensure that components in contact with the threader bar cannot touch any part of the magnetic equipment at earth potential.

BS 6072 states that amperage values required will be similar to those used in current flow techniques.

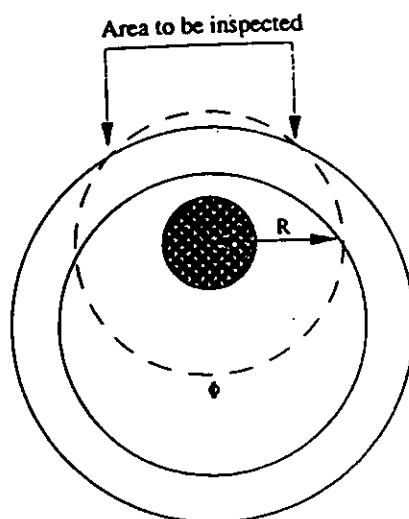


Fig. 4.7. Threader bar method using non-central conductor.

NOTES

The area on the external surface of the test specimen which is to be viewed when using the non-central conductor method, is governed by the following formula:

$$R = \frac{I}{15}$$

Where:

I = the peak current value (r.m.s. $\times 1.414$ = peak current)

R = radius of the inspected surface

Encircling coils

This technique consists of placing the specimen inside a coil of tubular or solid construction, through which a low voltage, high amperage current is passed. The magnetic field passing through the centre of the coil - typically three or five turns - creates longitudinal magnetization and is therefore used to detect defects which lie transverse to the components major axis.

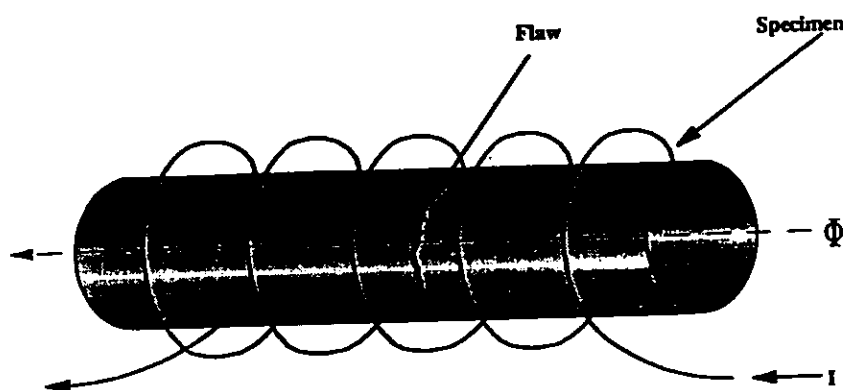


Fig. 4.8 Encircling coils produce longitudinal magnetism in the specimen which is used to detect transverse flaws. The coil may be flexible or rigid.

For practical purposes only defects which lie within the confines of the coil should be interpreted although the field will extend for 100 to 150 mm beyond either end.

If the specimen being tested has a small diameter in relation to the inside diameter of the coil, it should ideally be positioned close to one side of the coil and rotated to obtain the best results.

Current values for the rigid coil technique may be obtained from the BS 6072: where the component occupies less than 10% of the coil cross-sectional area and lies adjacent to the coil wall the following formula may apply:

$$NI = \frac{K}{LD}$$

$$I = \frac{K}{(LD) \times N}$$

Where:

NI = ampere/turns.

N = the number of turns in the coil.

I = the current in amperes.

L = the component length.

D = the component diameter.

(for non circular components D = Perimeter divided by 3.142).

L/D = the ratio of these two values ($L \div D$).

K = the constant (see below).

NOTES

The constant K taken from BS 6072:

- 32,000 for the mean value of a d.c. source and for the peak value of any waveform.
- 22,000 for an a.c. source (r.m.s. value) and for full-wave rectified current (mean value).
- 11,000 for half-wave rectified current (mean value).

The L/D ratio should not be less than 5:1 or more than 20:1; the ideal ratio is between 12:1 and 15:1.

Example 1:

What ampere/turns would be required in accordance with BS 6072, to test a specimen 200 mm long and 25 mm diameter, using a half-wave rectified current rigid coil?

- a. $NI = ?$
 $N = 3$
 $L = 200 \text{ mm}$
 $D = 25 \text{ mm}$
 $L/D = 200 \text{ mm} \div 25 \text{ mm} = 8$
 $K = 11,000$
- b. $NI = \frac{K}{L/D}$
- c. $NI = \frac{11000}{200/25}$
- d. $NI = \frac{11000}{8}$
- e. $NI = 1375$

Example 2:

What amperage would be required in accordance with BS 6072, to test a specimen 450 mm long and 50 mm diameter using an a.c. coil with 5 turns?

- a. $I = ?$
 $N = 5 \text{ turn coil}$
 $L = 450 \text{ mm}$
 $D = 50 \text{ mm}$
 $L/D = 450 \text{ mm} \div 50 \text{ mm} = 9$
 $K = 22,000$
- b. $I = \frac{K}{(L/D)} \times N$
- c. $I = \frac{22000}{(450/50)} \times 5$
- d. $I = \frac{22000}{9 \times 5}$
- e. $I = 489 \text{ amps}$

When using any of the current flow or threader bar methods, the field strength is largely determined by the current (amperes) flowing in the circuit. When using any

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form of coil the field strength is determined by the current flowing in the circuit and by the number of turns in that coil, thereby obtaining ampere/turns.

The number of ampere/turns can be applied to the specimen length in metres to give the field strength unit for coils as *ampere turns/metre (AT/m)*.

Flexible cables

When a single conductor is used, the magnetic field reduces rapidly at increasing distance from the conductor; this restricts the production of an adequate test area with a sufficiently constant magnetic field. If the current is made to flow in the same direction through conductors spaced some distance apart, a relatively constant field is produced.

Flexible cable techniques can be used on a considerable variety of component shapes. Configurations used are normally obtained with a heavy insulated flexible cable which is placed through, on, or around the specimen. A current passed through the coil will then induce a magnetic field into the test piece.

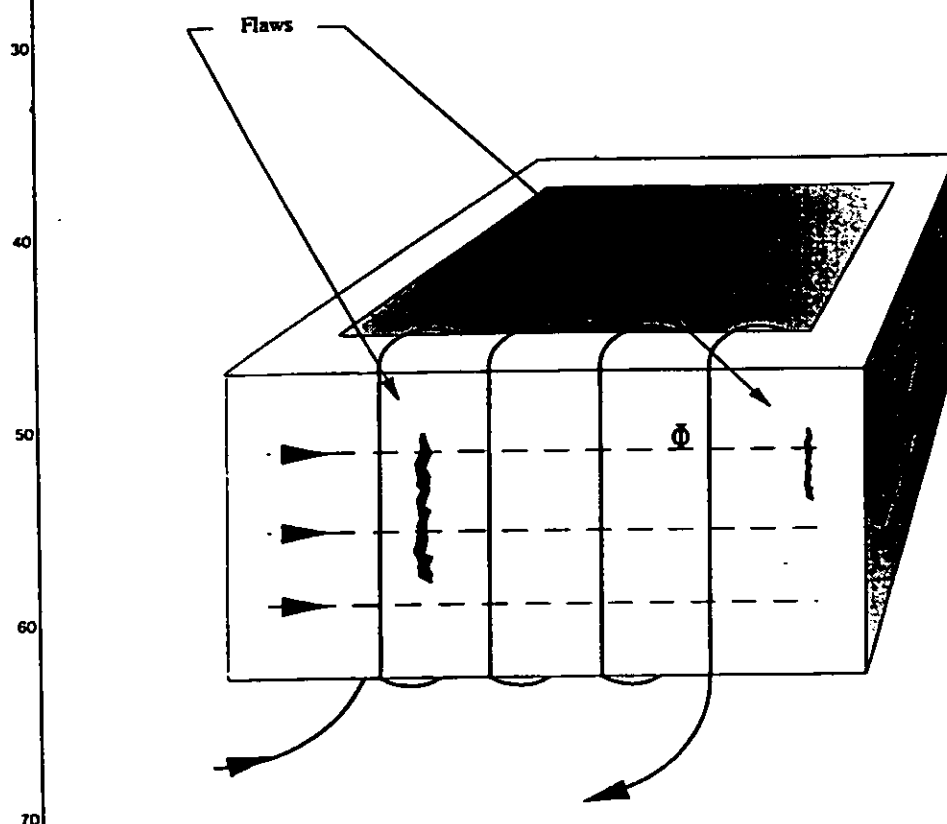


Fig. 4.9. Threader cable technique.

Defects lying parallel to the cable will be the most readily detected. On complex shapes the position and method in which the coil is wound may have to be found by experimentation to ensure an adequate field in all areas.

One method of test utilising flexible cables is the *adjacent cable technique*. This method of magnetization requires the material being tested to be in close proximity to a current flowing in one direction.

The return cable for the electric current must be arranged to be as far removed from the inspection zone as possible and, in all cases, this distance should be greater than $10d$. Where d is the width of the inspection area, expressed in millimetres.

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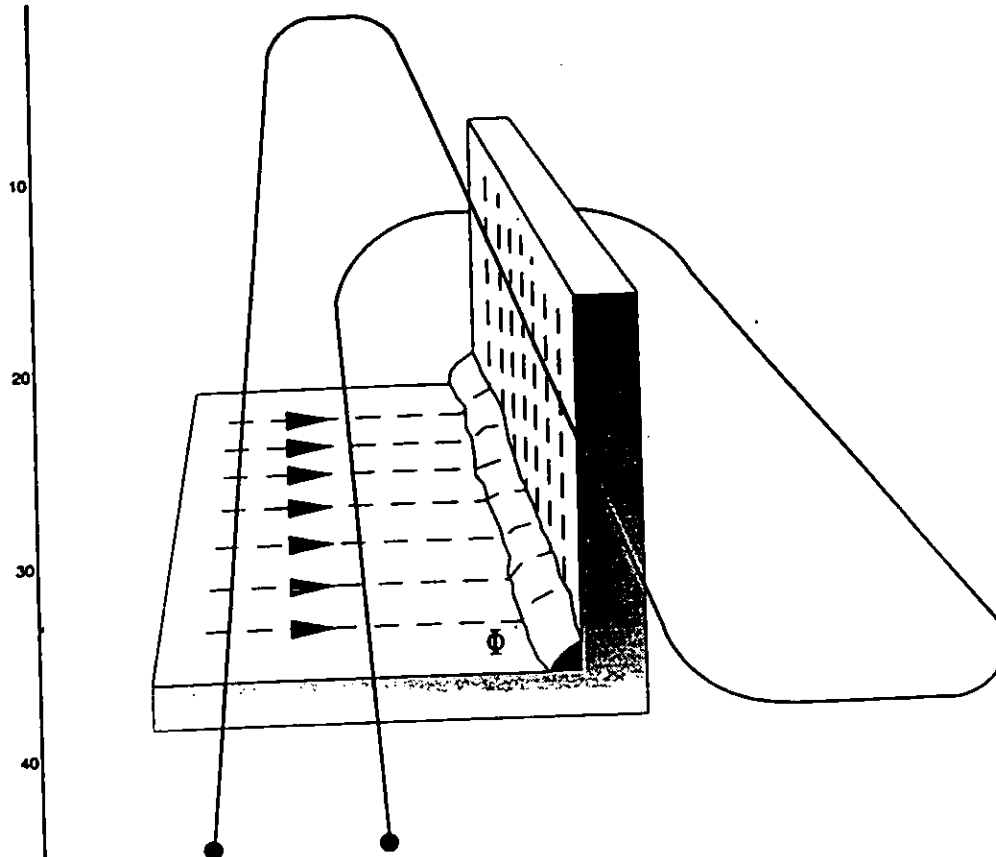


Fig. 4.10. Adjacent cable technique.

When testing radiused corners on cylindrical components or branch joints, e.g. stub to header welds, the cable may be wrapped round the surface of the component or the branch, and several turns may be bunched up in the form of a closely-wrapped coil. In this case, the surface inspected shall be within a distance, d , of the winding, where $d = NI/30$, when NI = number of turns $\times$ amps.

Advantages of flexible cable techniques include:

- A.c. or d.c. fields.
- Large areas inspected with each set-up.
- No poles to attract magnetic particles.
- Field strength can be altered.
- Predictable field strengths.

Disadvantages include:

- Cumbersome long heavy cables required.
- Longer setting up times.
- Heavy transformer required for large amperages.

NOTES

The detecting media should normally be in accordance with BS 4069 - *MPI inks and powders*. When inks are used for MPI the test may be referred to as a *wet method*; when powders are used the test may be referred to as a *dry method*.

The basic requirements for magnetic particles are as follows:

- a. Fine grains to reduce the gravitational effect. The maximum grain size is specified in BS 4069 as 200 μm for powder, 100 μm for inks. However, if the grains are too fine this could coagulate the particles.
- b. Elongated shape for easier polarization. Spherical particles are also needed to ensure dispersal over the surface.
- c. High permeability for magnetization in weak flux leakage fields.
- d. Low retentivity if particles are to be removed from the test surface after the test.
- e. High contrast against the background of the test surface.

Dry powders

Dry powders consist of finely divided ferromagnetic particles available in a variety of colours, e.g. black, grey, red, orange or yellow, some dry powders may also be fluorescent.

Dry powders are usually applied to a surface by means of a puffer device, they should be floated, not blasted, onto the area under test.

Dry powders should ideally be used with a.c. or half-wave rectified current (h.w.r.c.) because of the extra mobility that these current types impart onto the powder.

Dry powders must be used when MPI is being carried out on hot surfaces, a situation where inks would obviously not be suitable. Dry powders are also encountered for use on rough surfaces.

Inks

Ferromagnetic particles suspended in a suitable carrier fluid should have the same basic properties as the dry powders. There are two distinct divisions when dealing with MPI inks, these being *fluorescent inks* and *non-fluorescent inks*. Non-fluorescent inks are usually black and referred to as *black inks*.

In accordance with BS 4069, the composition of inks shall be as follows:

- Ferromagnetic particles in non-fluorescent inks should not be less than 1.25% and not more than 3.5% by volume.
- Ferromagnetic particles in fluorescent inks should not be less than 0.1% and not more than 0.3% by volume

Carrier fluid, which may be oil based, e.g. paraffin, or water shall make up the volume to 100%.

If water is used it should contain additives to prevent corrosion of the surface or particles, and improve the wetting action. Paraffin based products have good wetting action, are odourless, have a relative tolerance to oil or grease on the surface and are not corrosive.

BS 4069 gives the following method of test for assessing the solid content of magnetic inks:

1. Maximum volume of magnetic ink for test should not exceed 5 litres.
2. Agitate container for not less than 5 minutes.
3. Pour sample of ink into 100 ml settlement flask (centrifuge type or Sutherland flask).

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4. Allow to settle for 60 minutes.
5. Read off the solid content to nearest 0.1 ml.

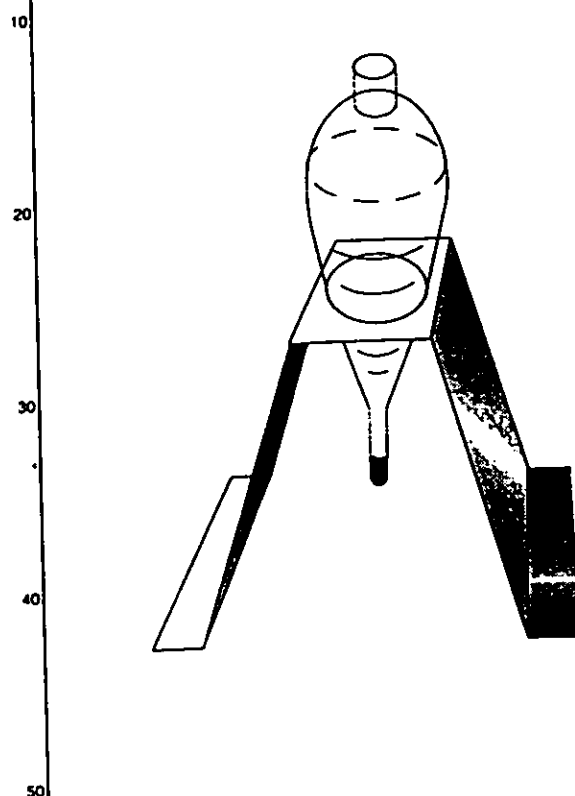


Fig. 5.1 Settlement flasks used to determine the solid content of MPI inks.

An additional test for fluorescent inks after settling is to check the suspension fluid with UV-A light, if a yellow-green fluorescence is observed the ink should be discarded and replaced with a fresh solution.

In general it is stated for all inks that:

- a. They shall form a uniform suspension when agitated.
- b. They shall not contain any other ingredients that are likely to cause injury to the operator either during or after use.
- c. The inks shall not corrode or otherwise adversely affect the surfaces of the workpieces.
- d. They may contain small quantities of other ingredients at the manufacturers discretion providing the solid content remains within the specified proportions.

Health and safety considerations

The supplier of MPI consumables is obliged to make available to the purchaser, all relevant health and safety data applicable to the supplied goods. The user also has an obligation to comply with the health and safety requirements. See also the COSHH Regulations in Unit MT11.

UNIT MT5 • THE DETECTING MEDIUM

NOTES

Specific health and safety considerations are:

Flammability: Read container labels for flash points. In accordance with BS 4069, if an oil base is used the flash point when assessed in a closed cup test shall not be less than 65°C.

Asthmatic: Do not use in confined spaces without masks or adequate ventilation.

Skin hazard: Use protective clothing.

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All areas under test using non-fluorescent inks should be adequately illuminated using artificial light if necessary. For fluorescent inks, a UV-A light with subdued background lighting should be used, the darker the better.

Non-fluorescent inks and powders

The area under inspection should be evenly illuminated. BS 6072 states a minimum illumination level of 500 lux in daylight or under artificial light.

Fluorescent inks and powders

In accordance with the BS 6072, the minimum UV-A irradiance level at the surface being inspected should be $800 \mu\text{W}/\text{cm}^2$ with a maximum background light intensity of 10 lux.

Fluorescence degrades with exposure to ordinary light over a period of several hours, moreover, it can be arrested entirely at high temperatures. As the intensity of the ultraviolet light is increased the amount of fluorescence increases.

UV-A light

Ultraviolet light is generated by mercury vapour lamps. The mercury is vaporised inside a quartz capsule by a small low current arc from an auxiliary electrode. After about 5 minutes there is sufficient mercury vapour in the capsule to initiate an arc between the main electrodes. The lamp should not be used for approximately 15 minutes to allow sufficient time for it to attain full working intensity.

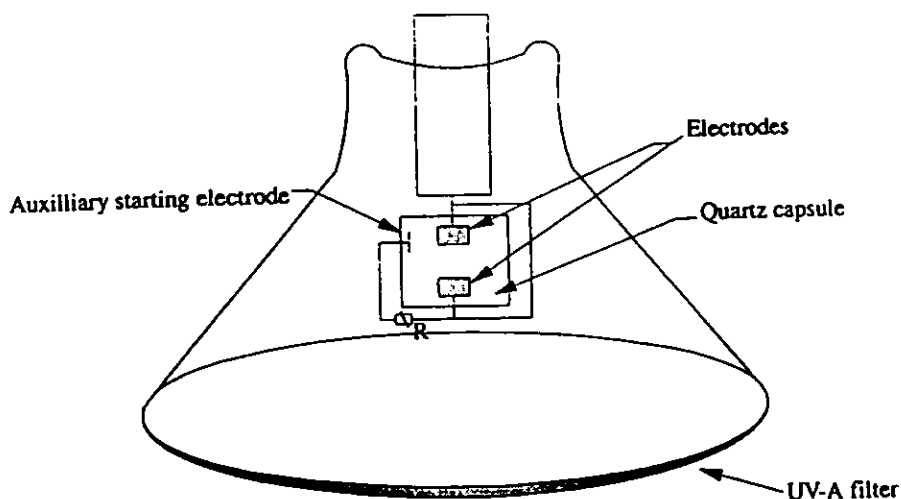


Fig.6.1. Ultraviolet (UV-A) lamp.

Assessment of UV-A intensity

The efficiency of the mercury vapour lamp can deteriorate quickly without any obvious effect, therefore the lamps intensity should be checked regularly with an ultraviolet light monitor, such as that specified in BS 4489 - *Method for assessing UV-A light used in non-destructive testing*.

BS 4489 gives information and recommendations for the testing of UV-A light sources, in particular the assessment of emission from new lamps and the regular testing of any lamps in service which may produce a drop in output after approximately three months use. The test is carried out using a fluorescent screen and a photometer.

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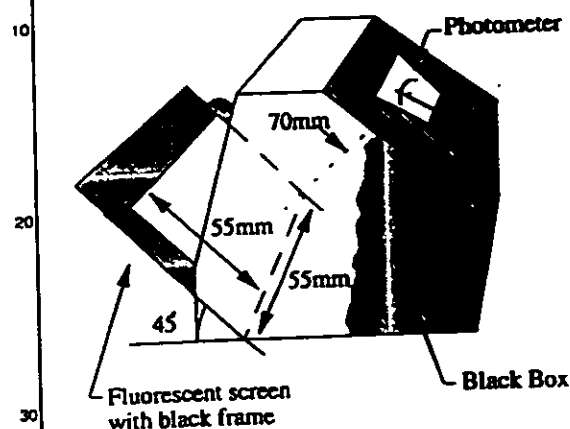


Fig. 6.2. Instruments for assessing intensity from a UV-A light source.

Safety

UV-A lights operate with wavelengths between 320-400 nm (3200-4000 Å), shorter wavelengths than this can cause injuries to the eyes. To prevent injury, a filter should be used which cuts out wavelengths below 320 nm.

Looking into a UV-A light will cause temporary clouding of vision due to the fluid in the eyeball fluorescing, it will normalise with no permanent effects after a few seconds, although it is important to note that prolonged exposure may cause cataracts.

NOTES

Demagnetization of a specimen may be required before testing, between successive shots/magnetizing positions, and/or after testing in order to remove any residual magnetism in the specimen.

Demagnetization may be carried out for the following reasons:

1. To remove any residual magnetism which may remain from previous MPI procedures or other sources, which may interfere with the subsequent test.
2. To remove any residual magnetism between successive MPI shots in the test procedure.
3. To remove any residual fields after MPI has been carried out so as not to interfere with other work processes, e.g. a residual magnetic field may attract cutting swarf during machining operations and may also interfere with subsequent welding operations causing *arc-blow*.

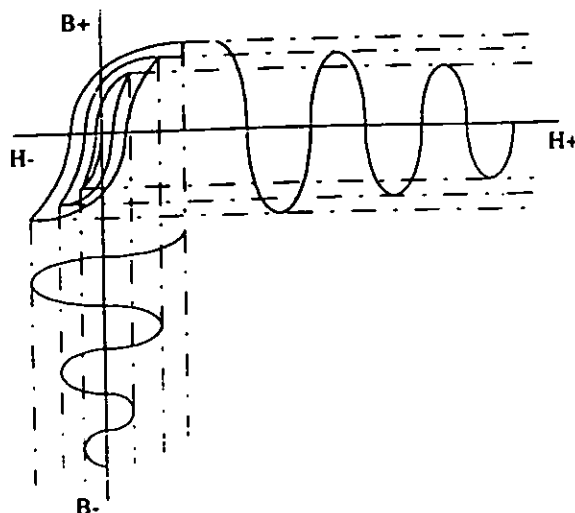


Fig. 7.1. Hysteresis loop showing demagnetization.

There are several methods of demagnetization:

- a. **Aperture coil with reversing a.c..**
This is a coil of several hundred turns which is connected to the mains. The object to be demagnetized is placed inside the coil and slowly withdrawn to a distance of at least 1.5 metres away from the coil, or the object is left stationary in the coil and the current gradually turned down to zero.
- b. **Aperture coil with reversing d.c..**
This method is similar to the a.c. coil but the demagnetizing field penetrates further in the test piece. The current direction is reversed periodically, but at decreasing amplitude until the residual magnetism is removed.
- c. **A.c. electromagnetic yokes.**
These can be used to demagnetise large areas *in situ*. The yoke is stroked over the surface, lifting it well clear (450 mm to BS 6072) between strokes.
- d. **A.c. current flow.**
When using a current flow crack detector, demagnetization can be carried out by using a.c. current and slowly reducing the current flowing to zero. A variation on this method is the peak and drop technique where the current is initially introduced at a higher value than the magnetizing current then reduced to zero, the peak current is then re-introduced at successively decreased values whilst returning to zero current after each peak current.

NOTES

c. **Flexible cable (Induction system).**

If a portable induction type crack detector is available, demagnetization can be carried out by wrapping 2 or 3 turns of the cable around the object to be demagnetized and gradually reducing the a.c. current to zero. If magnetization is carried out using the induction coil, the object under test is automatically demagnetized if the current is reduced to zero before the unit is switched off.

f. **Heat treatment.**

It is not necessary to demagnetise if a heat treatment process is to follow magnetic particle inspection and the specimen is to be heated beyond its curie point, which is approximately two thirds of the materials melting point, e.g. 358°C for nickel, 870°C for iron and 1127°C for cobalt. Above this level ferromagnetic materials lose their magnetism, i.e. the magnetic domains become randomly orientated.

When a material is to be demagnetized, by methods other than heat treatment, the initial demagnetizing field strength must be stronger than the residual field.

The level to which a specimen must be demagnetized may be laid down in an MPI test procedure or specification.

The amount of residual magnetism remaining may be checked with a calibrated *field strength meter* or existence may be confirmed with other types of field indicator.

UNIT MTS • MAGNETIC FIELD INDICATORS

NOTES

Magnetic field indicators, e.g. *flux indicators* and *field strength meters* are used to assess the presence, intensity and/or direction of a magnetic flux either before, during, or after testing. Specific uses of these instruments are as follows:

- To ensure MPI test machines are functioning correctly.
- To ensure that the specified field strength and field direction are apparent.
- To check for the presence of residual magnetism before testing.
- To check for the presence of residual magnetism after testing.

Magnetic field strength meters and portable flux indicators should not be used in conjunction with permanent magnets or with d.c. electromagnets for determining adequate flux density. A flux indicator may be used with these magnets but only to verify the suitability or correct application of an ink or powder.

Circular fields may be contained completely within a specimen, if this is the case, the field will not be detected.

Many terminologies are encountered when referring to types of magnetic field indicators, which can be confusing. There are also alternative methods other than those listed below to check for residual fields; *BS 6072* relates to a method involving a compass and also a method involving a paper clip on a thread.

Portable magnetic field strength meters

To measure residual magnetism, calibrated magnetic field strength indicators of the type which contains a soft iron vane are commonly used. The vane aligns itself with the magnetic field, the strength and direction of the field is measured by the meter calibrated in gauss or tesla's; similar non-calibrated instruments also exist. Neither of these instruments should be brought into close contact with any strong magnetic fields as this may cause damage to the instrument.

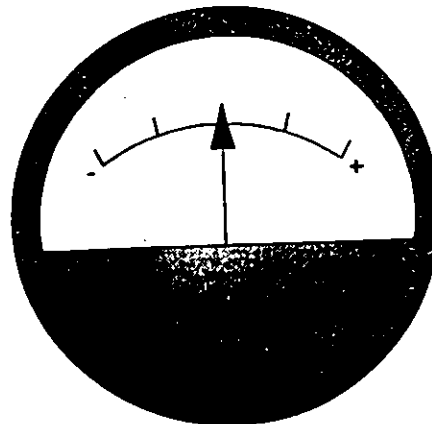


Fig. 8.1. Field strength meter.

Burmah-Castrol strips

These are small brass or silver finish strips containing artificial defects (3 slots) in Mu metal; Mu metal is a highly permeable material containing nickel, manganese and iron. The brass finish strips are commonly used in general engineering applications and indicate low field strengths. The silver finish strips will show higher field strengths and are used in aerospace industries or areas that require a more critical examination.

UNIT MTS • MAGNETIC FIELD INDICATORS

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In either case, if the field is strong enough, three linear indications will show on the strip; they should be rotated on the specimen surface to define field direction.



Fig. 8.2. *Burmah-Castrol strip.*

With reference to the brass finish strip (type 1), if no indications are apparent the field is too weak for inspection and it is below 3 amps a.c. r.m.s./mm (240 Oe). Three indications show that the field strength is greater than 5 amps a.c. r.m.s./mm (400 Oe).

With reference to the silver finish strip (type 2), if no indications are apparent the field is below 5 amps a.c. r.m.s./mm (400 Oe). Three indications show that the field strength is greater than 15 amps a.c. r.m.s./mm (1200 Oe) and the field is suitable for critical inspection.

Note: The above figures are based on a mild steel bar.

The ASME field indicator

This consists of eight sections of mild steel brazed together, the separating lines between the sections forming artificial defects. One side also has a chromium coating applied, this has a greater sensitivity than the opposite side which shows surface breaking defects.

When the indicator is placed on a magnetized component the magnetic field passes through the indicator. The separating lines between the sections become visible when the detecting media is applied. To determine the direction of the magnetic field the indicator should be rotated until one of the lines is perfectly visible, at this point the direction of the field is at 90° to the line.

Fig. 8.3. *ASME field indicator.*

NOTES

The Berthold penetrameter

This field indicator contains two artificial defects at 90° to one another. There is a sensitivity adjustment consisting of a cover plate which can be turned to one of four settings which vary the distance of the artificial defects from the surface under test; the greater the gap the higher the field strength necessary to render the lines visible. They are used in a manner similar to the ASME indicator.

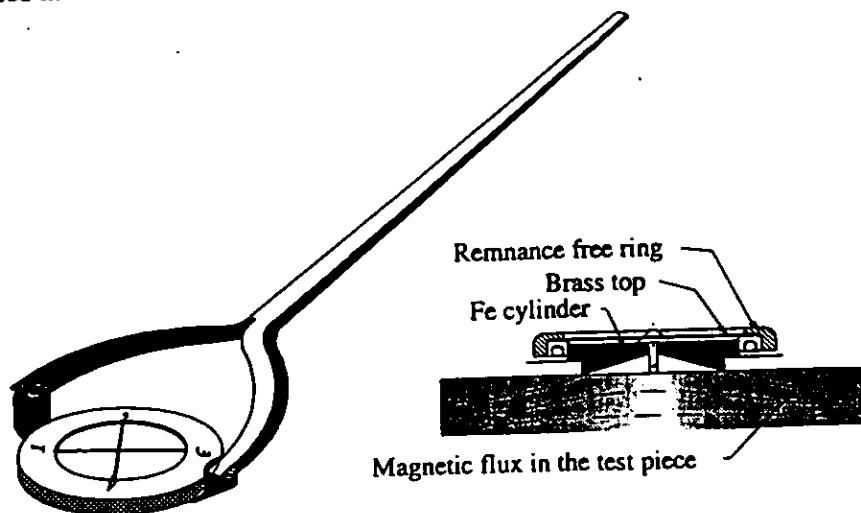


Fig. 8.4. Berthold penetrameter.

Hall effect meters

These instruments are usually used in laboratory type environments to measure tangential, normal, or axial fields depending on the probe design. Hall effect meters use, as their name suggests, the *Hall effect principle*.

An electric current is passed through a small semi-conducting crystal contained within a probe. A voltage is generated across the crystal, when the probe is placed in a magnetic field, the magnitude of this voltage is directly proportional to the magnetic flux density within the probe. The relative permeability of the semi-conducting crystal is very close to one, so the voltage generated is proportional to the magnetic field strength at the point where the probe is placed. The voltage generated by the probe is measured by an electronic circuit and indicated on a meter marked in units of field strength.

The Hall effect meter is calibrated with a series of standard magnets which provide known values of field strength within the working range of the instrument. Manufacturers supply a zero-field chamber which is required to set the zero. If the peak value of a time-varying field is required, the meter reading is multiplied by a conversion factor, the value of which depends upon the shape of the waveform and upon the measuring principle employed by the instrument.

NOTES

Performance checks to BS 6072

Performance checks are used to ensure an MPI test system is functioning correctly, i.e. a magnetic field is capable of being produced and reproduced so that test results can be maintained at a consistent level.

Current flow (headshots)

When current flow techniques are used on bench units, the following test should be carried out for each wave form available for use:

- Ensure the test piece is thoroughly demagnetized and pre-cleaned satisfactorily.
- Position the test piece (see diagram below) between the head and tailstock of the bench equipment.
- Slowly introduce a current and apply ink until the first hole (closest to the external surface) is visible.
- Note the applied amperage and continue to apply the current progressively until the second and third holes are noted.

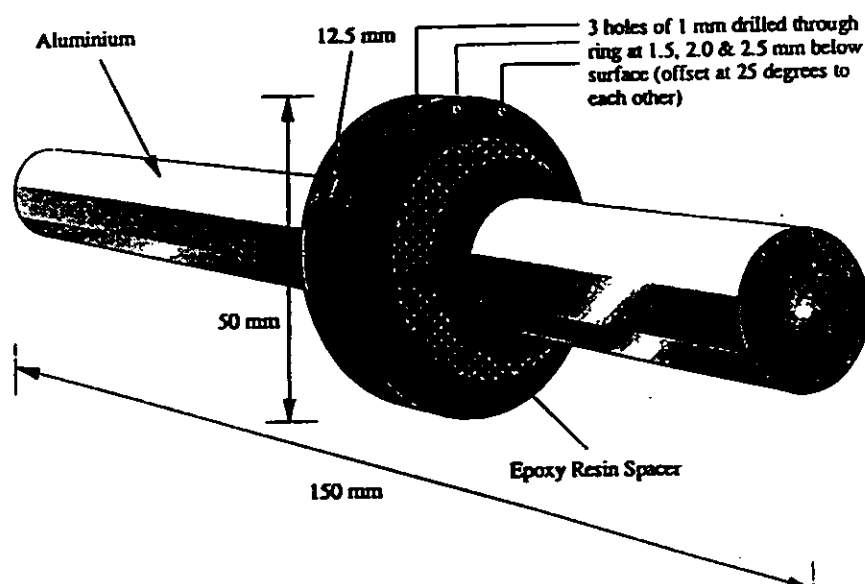


Fig. 8.5. Test piece for current flow technique.

Magnetic flow

If magnetic flow is being used, a similar procedure to the above would still apply, except that dial readings/switch settings would be taken instead of amperage values and the following test piece would be used.

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The British Standard recommended test block only has one test hole, whereas the Rolls Royce test block has five holes.

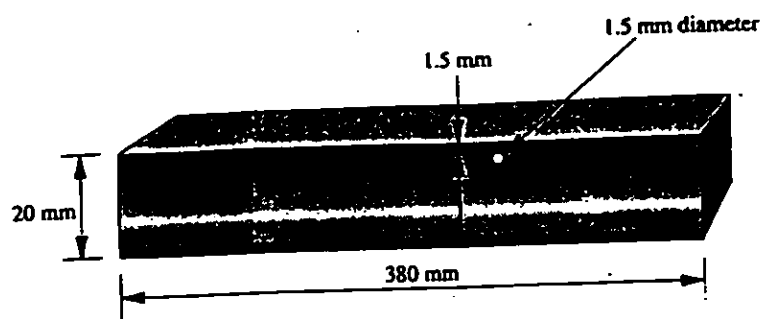


Fig. 8.6. Test piece for magnetic flow and rigid coil techniques.

Rigid coil

If a rigid coil is being used, the procedure in the section above for *Current flow (headshots)* would still apply, except that the test piece used would be as shown in previous section for *Magnetic flow*.

NOTES

Adequate reporting is essential for the transmission of relevant and correct information after the test. Any test report should include the information required by the relevant specification for the work being performed. The *BS 6072* requires the following information as a minimum:

- a. work location;
- b. description and identity of the component tested;
- c. date of test;
- d. stage of test, e.g. before or after heat treatment, before or after final machining;
- e. reference to the written test procedure and the technique sheets used;
- f. name of the company;
- g. name and signature of the person performing the tests;
- h. the test results.

If a written procedure is absent, the *BS 6072* also requires the following information on the report:

- a. description of equipment used;
- b. technique of flux generation;
- c. indicated current values and waveform for each technique used;
- d. distance between contact areas or dimensional details of coils, etc;
- e. detection medium used and background;
- f. surface preparation;
- g. viewing conditions;
- h. method of recording or marking of indications.

A common method of recording indications is to reproduce indications on a scaled diagram. Indications should be drawn with references to a datum on the test piece. The diagram(s) should not be overloaded with too much information; use two diagrams if necessary. A separate diagram showing magnetizing techniques should ideally be included where it is not obvious which technique has been applied.

Other methods of recording indications are:

- a. Photographs.
- b. Clear sticky tape to peel the dried magnetic particles indication from the test piece.
- c. Propriety lacquers sprayed on wet; when dry the resultant film is then peeled away with the indication.
- d. Magneto-graph.
- e. Magnetic sachets with light sensitive paper backings.

Prior to the recording of indications, it is essential to ensure that the test conditions, and in particular, the magnetizing levels are as near as possible to the level recommended for the technique.

If dry powder is used, no preparation is necessary. If any oil based carrier fluid is used, the surface should be drained and adequately dried. Another possibility is to retest the workpiece using a magnetic ink made with a volatile carrier fluid.

Preservation of indications to BS 6072

To obtain a permanent record, either photography or one of the methods given in (a) to (f) should be used. It is essential that a common datum be established on both the workpiece and the record and that care be taken not to disturb the indications.

- a. Cover the indications with a transparent adhesive film. Carefully peel off the film and the adhering indications and reapply to either paper or card of contrasting colour.

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- b. Degrease the test surface, cover with a white matt adhesive film and retest. After drying, if necessary, cover the indications with a clear film in the manner described in (a) and transfer together the pair of films to the record card.
- c. Spray the tested area with a quick-drying, strippable coating. Strip off this coating and view the face previously in contact with the workplace, to which the indications will be transferred.
- d. Heat the workplace to an approved temperature and, without delay, slowly immerse in a powdered plastic material and slowly withdraw. Allow it to drain and cure it in accordance with the manufacturers instructions. Strip off the coating complete with indications from the workpiece and view the face previously in contact with it.
- e. Degrease the test surface and coat with a proprietary, strippable, magnetic-oxide paint. Magnetise the part to saturation and peel off the coating. If it is dipped in agitated magnetic ink, it will reveal the flaw indications on the oxide film.
- f. Degrease the test area and coat with a proprietary self curing magnetic silicone-rubber compound. Magnetise to saturation and allow the compound to cure. The oxide in the compound will migrate to the position of any flaw and, when removed from the workpiece, the rubber previously in contact with the surface will show the flaw.

Limitations of preservation methods

Methods (a) to (c) above are generally restricted to surfaces of simple geometric form because of the difficulties involved in removing the films. Method (d) does not generally produce satisfactorily results from fluorescent magnetic inks as compared with black magnetic inks.

Photographic records

When a photographic record is made, the resulting photograph of the tested surface should, if possible, be actual size. If the surface of the workpiece is highly polished, care should be taken to avoid highlights. The use of a matt-contrast medium applied prior to testing may be desirable.

NOTES

Magnetic particle inspection using electrical apparatus can use several types of current, each form has advantages and disadvantages.

Alternating current

For all practical purposes alternating current (a.c.) is used to detect surface defects. A.c. does not penetrate deeply into the metal but produces a high density field near the surface of a ferromagnetic conductor, this characteristic is called the *skin effect* and will emphasise surface breaking discontinuities, e.g. fatigue or stress induced cracks. The skin effect is caused by the concentration of eddy currents near the surface of the specimen; eddy currents are only produced by an alternating current.

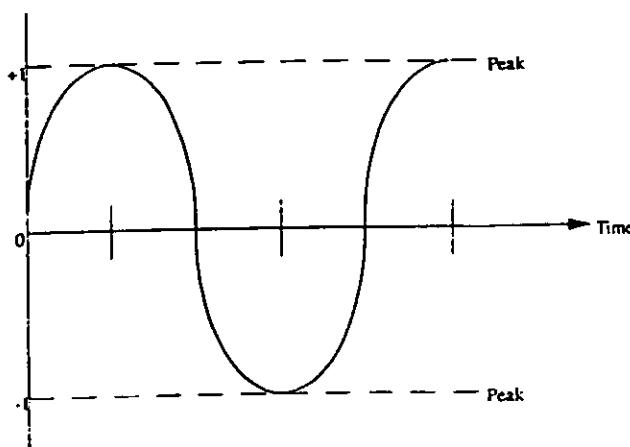


Fig. 10.1. Alternating current.

If surface breaking defects are the prime consideration for detection, then an additional advantage of a.c. is that *less relevant* indications from sub-surface discontinuities are not created by the low penetration capabilities of this type of current, which may otherwise distract the inspector.

Other advantages of a.c. include:

- Current at required values can normally be obtained directly from the mains supply, or via simple transformers.
- A.c. machines are relatively inexpensive, are easy to maintain and have basic operating characteristics.
- Due to the current form fluctuation (negative to positive), magnetic particles will vibrate and readily align themselves to flux leakages; this enhances the definition of defect indications.
- If after magnetization the current is reduced to zero via a rheostat or step down device the component is automatically demagnetized.

Disadvantages:

- The main disadvantage of a.c. is that it will only detect surface defects with any degree of reliability.

Direct current

A major advantage of d.c. for magnetization is its deeper penetration into the metal thus enabling sub-surface discontinuities to be revealed. D.c. also leaves residual magnetism which will hold an indication and allow more time for evaluation of the

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indication, however residual magnetism is not always an advantage and may present problems if complete demagnetization of the component is required. D.c. current may be obtained in various forms, either from batteries or rectified a.c., each having their own advantages and disadvantages.

Direct current from battery packs

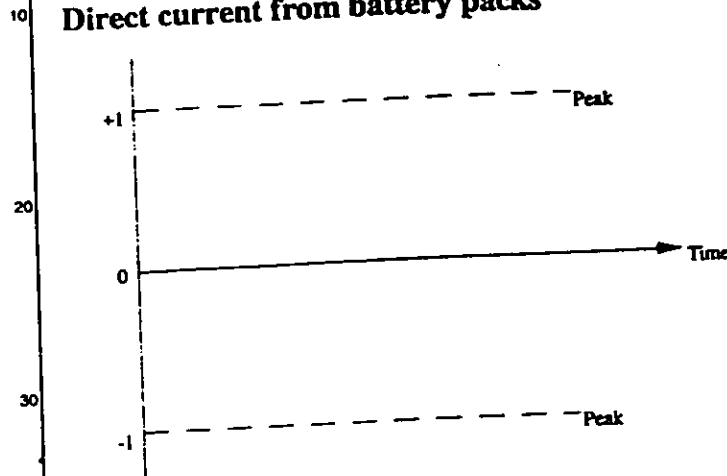


Fig. 10.2. Direct current from battery.

Advantages include:

- Does not require mains electrical supply.
- Sub-surface defects may be detected.

Disadvantages include:

- Weight of batteries.
- Limited battery life (high current draw).
- Continuous current flow does not produce particle vibration and will not therefore enhance defect detection. Because of this, continuous d.c. should not be used with dry powders which require a pulsating magnetic field to provide mobility to the powder when it lands on the test surface.

Half-wave rectified current

H.w.r.c. is achieved by removing all the negative current values from a.c. allowing the positive half cycles to remain, this current may be considered to be a form of d.c. with all the associated characteristics of this current form with the added advantage of a pulsating wave.

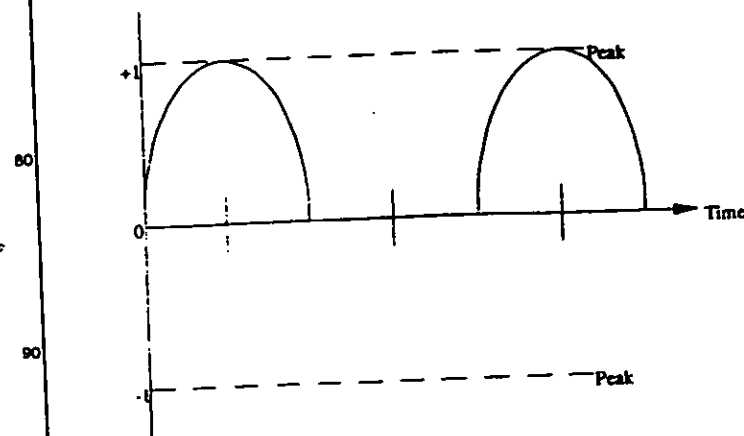


Fig. 10.3. Half-wave rectified current.

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Since h.w.r.c. will leave a component partially magnetized it is usually packaged as an a.c./h.w.r.c. unit so that the a.c. is available for demagnetization.

Advantages include:

- Will detect sub-surface defects.
- Will detect fine surface breaking defects.
- Simple, effective and inexpensive current form to achieve.
- Due to pulsating current the magnetic particles will vibrate and provide greater attraction to flux leakages.

Disadvantages:

- May leave the part partially magnetized.
- Full-wave rectified current.

Full-wave rectified current

F.w.r.c. provides the most efficient conversion of a.c. power to d.c.. With this current form the negative half cycle of an a.c. waveform is removed from below the zero line and reversed to make all values positive (or vice versa).

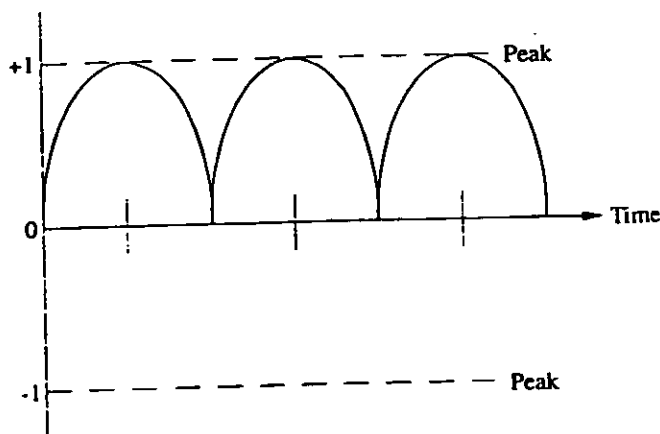


Fig. 10.4. Full-wave rectified current.

Advantages include:

- Detection of sub-surface defects.
- Simple and efficient means of providing direct current.

Disadvantages include:

- More expensive than h.w.r.c..
- Particle vibration and mobility reduced.
- Higher current requirements than a.c. or h.w.r.c..
- Can produce demagnetization problems.

NOTES

Scope

The Control of Substances Hazardous to Health Regulations 1988 came into force 1st October 1989. These regulations, referred to as The COSHH Regulations, define a substance hazardous to health as:

- a substance listed in part 1A of the approved list as dangerous for supply, see Classification, Packaging and Labelling Regulations 1984(b) - nature of risk classified as very toxic, toxic, harmful, corrosive or irritant.
- one which has an MEL in Schedule 1 of COSHH or if the H & S Commission has approved an OES.
- a micro-organism which creates a hazard to health.
- dust in air (when substantial).
- a substance comparable with the above.

The COSHH regulations are not applicable to the control of lead, radioactivity, explosive or flammable properties of materials, high or low temperatures, high pressures, medical treatment or below ground work (mining).

Responsibilities

The exposure of an employee to substances hazardous to health is under the control of the employer. A training organisation is responsible for exposure by trainees.

Employers must prevent exposure to substances hazardous to health, or control exposure when total prevention is not reasonably practicable. Personal protective equipment, e.g. masks, are a second choice for control.

Employees have a duty to report any problems in exposure control procedures or any defects found in protective equipment.

Employers must keep records of examinations/monitoring tests carried out. These are kept for 5 years; 30 years for identifiable employees.

Occupational Exposure Limits (EH40)

The *Guidance Note EH40*, entitled *Occupational Exposure Limits*, is a document published by the Health and Safety Executive which gives occupational exposure limits for substances hazardous to health.

A solvent, which is a substance hazardous to health, has its own occupational exposure limit as given in EH40.

The toxicity value of a solvent is expressed in *parts per million (ppm)*, e.g. the occupational exposure limit for xylene is 100 ppm, this means to say that if the air contained xylene exceeding 100 ppm the air would be considered to be a significant hazard to health.

There are two types of occupational exposure limit:

- Maximum exposure limit (MEL): "is the maximum concentration of an airborne substance, averaged over a reference period, to which employees may be exposed by inhalation under any circumstances and is specified, together with the appropriate reference period, in Schedule 1 of COSHH."

The occupational exposure limit for xylene is an occupational exposure standard (OES), therefore the OES is 100 ppm.

NOTES

2. Occupational exposure standard (OES): "is the concentration of an airborne substance, averaged over a reference period, at which, according to current knowledge, there is no evidence that it is likely to be injurious to employees if they are exposed to inhalation, day after day to that concentration, and which is specified in a list approved by HSE."

When a MEL is specified, exposures must be kept as low as is reasonably practicable, but always below the specified value.

An OES should not be exceeded, but, an exposure over the limit is acceptable providing that the reason for exceeding the OES has been identified and measures are taken to reduce the exposure below the OES as soon as is reasonably practicable.

LEVEL 2 - MAGNETIC PARTICLE TESTING - GENERAL

PAPER No. MT1G2

NAME:

COMPANY:

DATE:

SIGNED:

RESULTS:

1. A desirable property of magnetic particles used for the inspection medium for either the dry or wet method, is that they:
☒ A. possess high permeability.
☐ B. possess high retentivity.
☐ C. be non-magnetic.
☐ D. all of the above.
2. The accumulation of particles held at leakage field on a components surface is called:
☒ A. a discontinuity.
☐ B. a defect.
☒ C. an indication.
☐ D. magnetic writing.
3. If a copper conductor is passed through a ferrous cylinder and a current is passed through the conductor, then the magnetic field (flux density) in the cylinder will be:
☒ A. the same intensity and pattern as in the conductor.
☐ B. greater than in the conductor.
☒ C. less than in the conductor.
☐ D. the same regardless of its proximity to the cylinder wall.
4. A magnetizing force of one oersted produces:
☒ A. 1 gauss
☐ B. 1 Tesla
☒ C. 1 Weber
☐ D. 10^4 Tesla
5. Materials which are repelled magnetically are called:
☒ A. paramagnetic.
☒ B. diamagnetic.
☐ C. ferromagnetic.
☐ D. non-magnetic.

BS 6072 Methods for MPI.
BS 4069 Inks.
BS 3683 Terms.
BS 5044 Contrast Paints.

6. How many gauss in a tesla?

- A. 10^{-7}
- B. 10^{-4}
- C. 10,000,000.
- ☒ D. 10,000.

7. The end of a bar magnet at which the lines of force (flux) are thought of as entering the bar is:

- ☒ A. the south pole.
- B. the north pole.
- C. both the north and the south pole.
- D. the ferromagnetic end.

8. An ASME indicator/penetrameter may be used in MPI:

- A. to detect diamagnetic wandering.
- ☒ B. in a similar manner to a Berthold penetrameter.
- C. to measure fluorescent ink suspensions.
- D. to check the drying time of contrast paint.

Brass Type N°1

9. What is the curie temperature of a ferromagnetic material?

- A. The temperature at which it becomes radioactive.
- B. The temperature at which it loses its radioactivity.
- ☒ C. The temperature at which it loses its magnetism.
- D. The temperature at which it becomes magnetic.

10. The build up of a non-relevant indication due to a sharp contour change in the test component is referred to as:

- ☒ A. a defect.
- ☒ B. furring.
- C. magnetic writing.
- D. a Tesla.

Correct term.

11. Which British Standard relates specifically to MPI inks and powders?

- ☒ A. BS 6072.
- ☒ B. BS 4069.
- C. BS 3683.
- D. BS 6443.

12. A 5 turn coil around a part produces:

- ☒ A. a longitudinal field.
- B. a circular field.
- C. either a circular or longitudinal field depending on the direction of current flow.
- D. an intermittent field.

13. Which of the following MPI test methods may be used for detecting longitudinal defects on pipe external surfaces:

- ☒ A. The threader bar method.
- B. Rigid coils around the pipe.
- C. Flexible cable wrapped around the pipe making a coil.
- D. All of the above.
- E. 'B' and 'C' only.

14. The strongest magnetic field in a coil is at the:

- A. centre.
- B. end.
- C. outside edge.
- ☒ D. inside edge.

15. Which of the following will produce circular magnetism:

- A. A.C. yokes.
- B. Passing current through a coil.
- ☒ C. Prods.
- D. All of the above.

AC - only detects surface-breaking defects.

16. 1 Weber per m² is:

- A. a measurement of flux density, which equals 1 line of flux per cm².
- ☒ B. a magnetizing force which produces 1 line of flux per cm².
- ☒ C. equal to 1 Tesla.
- D. a new term which has replaced oersted.

AC = 5.3 amps per 1mm of Gap.
DC = 7.5 " " " "

17. How many amps are necessary to test a 25mm diameter, 200mm long, round steel bar with a 5 turn DC coil, in accordance with the requirements of BS 6072

- A. 4000 amps.
- ☒ B. 1280 amps.
- C. 256 amps.
- ☒ D. 800 amps.

$K/LD \times EN$

18. In accordance with the relevant British Standard, what is the specified percentage of fluorescent particles to the base:

- ☒ A. 1.25 to 3.5% — Black.
- B. 0.8 to 3.5%.
- ☒ C. 0.1 to 0.3% — fluorescent
- D. 0.3 to 0.8%

19. 'H' on a B and H curve (hysteresis loop) represents:

- A. magnetic flux.
- ☒ B. magnetic flux density.
- ☒ C. magnetizing force.
- D. the saturation point.

20. A copper bar is placed inside a 5 turn coil, the amperage required to magnetically saturate it will be:
- A. in the range of 500 to 1000 amps.
 - B. dependant on the l/d ratio.
 - C. lower than that used for steel.
 - ☒ D. It is not possible to magnetically saturate a copper bar.
21. Which current type provides the deepest penetration when demagnetizing?
- ☒ A. AC.
 - B. DC reversing periodically.
 - C. HWDC.
 - D. The above current types cannot be used for demagnetizing.
22. What is coercive force?
- A. The magnetic force required to magnetically saturate a part.
 - B. The magnetic force required to magnetize a part.
 - ☒ C. The reverse magnetic force required to demagnetize a part.
 - D. The reverse magnetic force required to cause the poles of a magnet to rotate 180°.
23. How is the strength of a permanent magnet usually measured?
- A. In ampere turns.
 - ☒ B. By lifting a specified weight of steel.
 - C. By comparing it against a magnetometer.
 - D. In oersteds per inch of flux path.
- Handwritten notes for Q23: $DC = 18 \text{ kg}$, 150 mm prod spacing; $AC = 4.5 \text{ kg}$, 300 mm prod "
24. What sort of magnetic field is produced in a bar, by placing a north pole at one end and a south pole at the other?
- ☒ A. Current flow.
 - B. Circular.
 - C. Longitudinal.
 - D. Induced.
25. What would the hysteresis loop for magnetic ink particles look like?
- ☒ A. Narrow in comparison with that for a magnet.
 - B. Wide in comparison with that for a magnet.
 - C. Completely circular.
 - ☒ D. It is not possible to have a hysteresis loop for magnetic particles.
26. An example of an instrument for measuring the direction of a magnetic field is called a:
- A. Burmah-Castrol strip.
 - B. ASME penetrometer.
 - C. Berthold penetrometer.
 - ☒ D. All of the above.
27. Why is H.W.D.C. often used with dry powders, as opposed to D.C.?
- A. Because dry powders are not attracted to leakage fields caused by a direct current.
 - B. Because the powder retains a residual field with a direct current.
 - ☒ C. Because greater powder mobility is achieved when it lands on the test surface.
 - D. A.C. or H.W.D.C. is not used with dry powders.

28. Why are surfaces breaking cracks best detected with A.C. as opposed to D.C.?
- ☒ A. Because of the *skin effect* produced with A.C.
 - B. Because D.C. cannot detect surface breaking defects.
 - C. Because A.C. magnets are cheaper.
 - D. It is preferable to use D.C.
29. When checking a weld for defects with a permanent magnet, the magnet should be placed:
- A. transversely over the weld to look for longitudinal defects.
 - B. longitudinal with the weld to look for transverse defects.
 - ☒ C. at 45° to the weld to look for both transverse and longitudinal defects at the same time.
 - ☒ D. normally in positions 'A' and 'B' if specification does not state otherwise.
30. Which of the following statements is always true?
- A. MPI is better than dye penetrant testing.
 - B. Fluorescent inks are always yellow/green.
 - ☒ C. MPI can only be used on ferromagnetic materials.
 - ☒ D. All of the above.

Flexible Cable Technique

* Current used = $30 \times D$ *

Distance between each coil recommended at least 10mm.

RADIOGRAPHIC TESTING

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1 RADIOGRAPHIC TESTING—OVERVIEW

1.1 Principles

Radiography is carried out using x-ray machines or artificial gamma sources (radio-isotopes).

X-rays or gamma rays pass through the object to be radiographed and record an image on a radiographic film on the opposite side. The radiation reaching the film will be determined by the objects thickness and density, e.g. lack of root penetration in a weld will increase the amount of radiation falling on the film in that area due to a reduction in thickness.

It is the wavelength of the radiation which governs its penetrating power; this is governed by the kilovoltage (kV)¹ when using x-rays, and isotope type with gamma rays². The intensity of the radiation is governed by milli-amperage (mA) when using x-rays, and by the *activity* of the isotope type with gamma³.

When the film is processed a *negative* is produced. The thin areas of an object will be darker than the thicker areas, therefore most weld defects will show up dark in relation to the surrounding areas, exceptions are excess weld metal, spatter, copper inclusions and tungsten inclusions.

1.2 Radiographic quality

An overall assessment of radiographic quality is made by the use of *image quality indicators (IQI's)*—these usually consist of seven thin wires decreasing in thickness. They are pre-placed on the weld being examined and therefore show on the radiographic film. The more wires visible the better the *sensitivity*.

The *density*—degree of blackness—of a radiograph is also measured to ensure it lies within a specified range for optimum quality.

1.3 X-radiography versus gamma radiography

X-radiography requires bulky and expensive machinery in comparison with gamma radiography, but x-radiography generally produces better quality radiographs and is safer. X-ray machines can be switched on and off, unlike gamma sources.

1.4 Capabilities and limitations of radiography

A major advantage of radiographic testing is that a permanent record is produced, i.e. the radiograph.

A major limitation of radiography is that it will only detect defects which have significant depth in relation to the axis of the x-ray beam⁴, i.e. radiography will not usually detect plate laminations, lack of inter-run fusion or cracks perpendicular to the x-ray beam.

2 X AND GAMMA RADIATION

2.1 General

Radiation can be either *electromagnetic* energy, e.g. heat, visible light, infra-red, ultraviolet, x-rays, gamma rays; or *corpuscular* energy (sub-atomic particle energy), e.g. electrons, alpha, beta, neutrons.

¹ For x-radiography 150-300 kV is typically used on steel weldments up to approximately 40 mm total thickness.

² Cobalt 60 (Co60) has a very high penetrating power—very short wavelength—and can be used on materials up to 200 mm thick. Iridium 192 (Ir192) is commonly used on steel weldments up to 50 mm thick—this therefore produces longer wavelength radiation compared to Co60.

³ Activity is measured in Curies (Ci) or gigabecquerels (GBq).

⁴ As a rough guide: the minimum through thickness depth of a defect capable of being detected is 2% of the wall thickness in the same axis as the x-ray beam.

Ionising radiation causes the *charging* of particles, i.e. the formation of ions, in a medium such as air or radiographic film. Ionising radiation may be electromagnetic or corpuscular energy.

The two types of radiation we are mainly concerned with in industrial radiography are x-rays and gamma rays¹.

X-rays and gamma rays, like all types of electromagnetic radiation, are emitted in minute energy packets known as *photons* or *quanta*; x-rays and gamma rays only differ in their source of production.

2.2 Properties of x-rays and gamma rays

Both x-rays and gamma rays have the following properties:

1. They have no effect on the human senses.
2. They have adverse effects on the body tissue and blood.
3. They penetrate matter.
4. They move in straight lines.
5. They are part of the electromagnetic spectrum and therefore travel at the speed of light - $3 \times 10^8 \text{ ms}^{-1}$.
6. They obey the inverse square law.
7. They ionise gases.
8. They may be scattered.
9. They effect photographic emulsion.
10. They make certain materials fluoresce.
11. They may be refracted, diffracted and polarized.

2.3 Measuring radiation

Wavelength

The wavelength of x-rays and gamma rays is measured in nanometres (nm), $1 \text{ nm} = 10^{-9} \text{ m}$, or angstroms (Å), $1 \text{ Å} = 10^{-10} \text{ m}$. The wavelength of electromagnetic radiation governs its penetrating power: the shorter the wavelength the greater the penetrating power.

Short wavelength radiation has an adverse affect on final radiographic quality; it also more dangerous to living matter.

Radiation exposure

The unit of radiation *exposure*—which is related to the ionisation of air—is the coulomb/kilogram. The old unit, the roentgen, however is still widely used.

1 roentgen = 2.58×10^{-4} coulomb/kilogram (C/kg).

Absorbed dose

The unit used for measuring how much radiation has been absorbed is the gray. 1 gray = 1 joule/kilogram (J/kg), therefore the gray relates to energy acting on matter.

The old unit for absorbed dose—the rad—is still encountered; 100 rads = 1 gray.

Biological effect

The unit used for measuring the biological effect of radiation is the sievert. 1 sievert = 1 joule/kilogram (J/kg), therefore the sievert also relates to energy acting on matter.

The old unit for the biological effect of radiation—the rem—is still encountered; 100 rems = 1 sievert.

¹ Other forms of radiation are also involved in producing an image on radiographic film.

2.4 Gamma ray generation

Gamma rays used in industrial radiography are emitted from artificial radioactive isotopes¹—if a material is radioactive it spontaneously emits corpuscular and electromagnetic energy—the gamma radiation is a by-product produced from the disintegration of the radioactive isotope.

The *activity* or *strength* of a radioactive isotope is expressed in *curies (Ci)* or *becquerels (Bq)*. The higher the activity value, the greater the intensity of gamma rays produced.

1 becquerel = 1 disintegration per second;
 3.7×10^{10} becquerels = 1 curie;
 therefore: 3.7×10^{10} disintegrations per second = 1 curie.

For industrial radiography, it is usually more practical to talk in terms of *gigabecquerels (GBq)*:

Giga = 10^9
 1 gigabecquerel = 10^9 becquerels
 37 gigabecquerels = 1 curie.

Radioactive isotopes are used taking into consideration their *half-lives*; the *half-life* of a radioactive isotope is the time it takes for the activity to drop to one-half of its initial strength.

The activity of a radioactive isotope does not relate to the penetrating power of the gamma rays produced; penetrating power depends on the wavelength of the gamma rays produced and this depends on the specific radioactive element involved. For example, cobalt 60 (Co60) has a very high penetrating power—up to 200 mm of steel—because the gamma radiation emitted has a very short wavelength.

There are three main radioactive isotopes used for industrial radiography: iridium 192 (Ir192), cobalt 60 (Co60) and Ytterbium 169 (Yb169).

2.5 X-ray generation

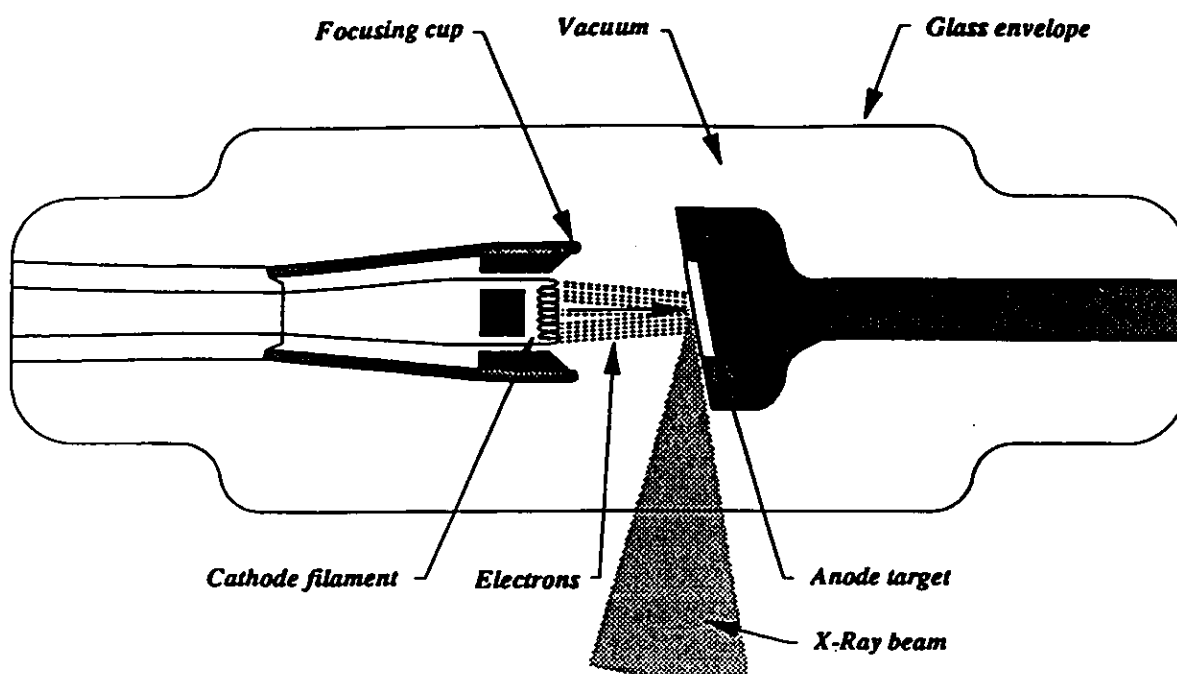
X-rays used in industrial radiography are produced from electrical machines usually referred to as *x-ray sets*; the x-rays themselves being produced from within an *x-ray tube* or *insert*.

An x-ray tube consists of an evacuated glass bulb, enclosing an *anode*—the positive electrode, and a *cathode*—the negative electrode. The cathode contains a filament within a curved reflector or *focusing cup*.

When the filament is heated to a white hot state by a current flow of a few amperes, electrons are emitted and are attracted towards the anode² in a concentrated beam formed by the focusing cup. The beam strikes a *target* set into the anode which results in the release of energy; this energy consists of approximately 97 to 99% heat and 1 to 3% x-rays for conventional x-ray tubes up to 300 kV.

¹ A radioactive isotope is an unstable state of a chemical element which has a different mass to the normal state of the *same* element.

² The anode is sometimes referred to as the *anti-cathode*.



Because of the high amount of heat energy produced, the anode is made from copper to conduct the heat away. But, copper has a low melting point, so to prevent the copper melting, a slip of metal with a high melting point is recessed into the anode at the point which is struck by the electron beam.

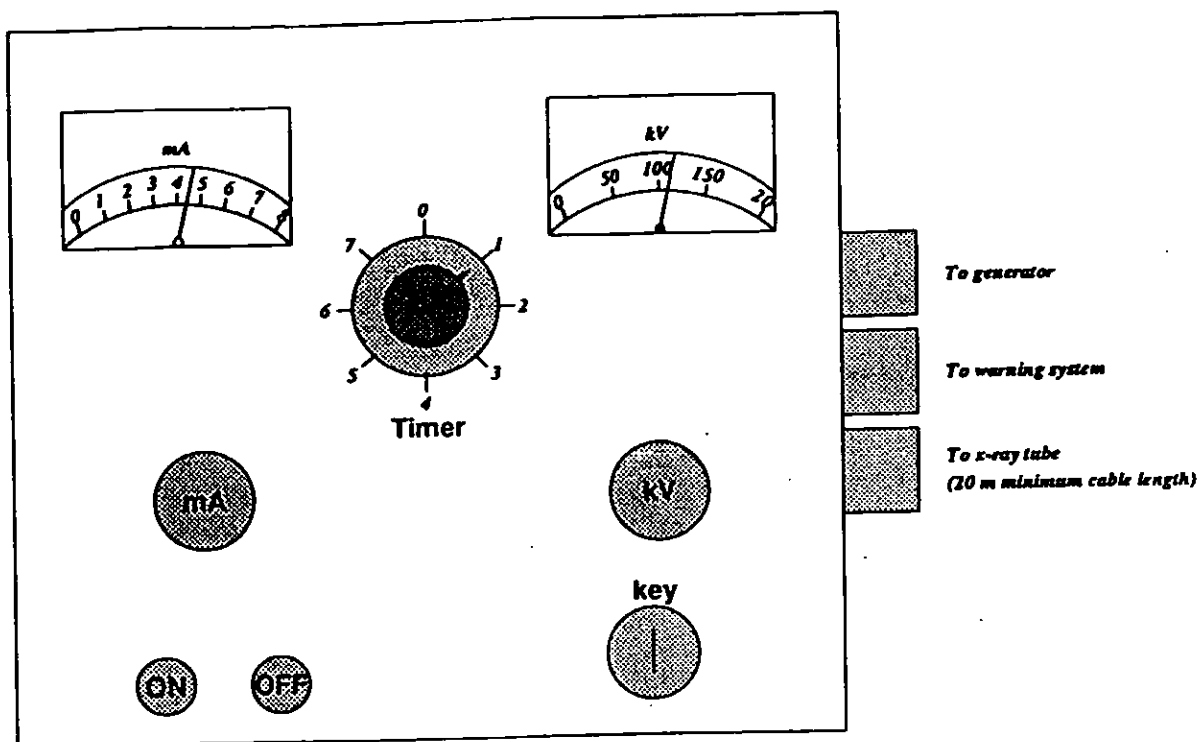
This slip of metal also serves another purpose, because, the higher the atomic number of the element struck by electrons, the greater will be the intensity and energy of the x-rays produced. This slip of metal, or target, is usually made of tungsten because of its high melting point of 3370°C , and its high atomic number of 74.

The area on the target which is struck by the electrons is called the *focal spot*; this area should be large enough to avoid local overheating, although from the radiographic image quality point of view, the focal spot should be as small as possible to provide good definition (sharpness) on the radiograph.

Additional cooling is required to cool the anode; gas, oil or water normally being employed for this purpose.

The cooling system and the insert are contained together in an earthed, lead lined container, the complete unit commonly being referred to as the *x-ray tubehead*. The tubehead is controlled from the *control panel*.

2.6 The x-ray equipment control panel



The three controls that govern a radiographic exposure using x-rays are the timer, the mA control and the kV control.

2.6.1 Timer

The timer is usually calibrated in minutes. The exposure time for an exposure is preset; when the equipment is activated, the timer counts down from the preset value. The exposure time will partially govern how much radiation is going to reach the film.

2.6.2 Milliamps (mA)

The mA controls the *intensity* or *quantity* of x-rays. When the mA is increased, the current flow through the filament is increased, which causes the filament to get hotter resulting in an increase in the intensity of electrons released. The greater the intensity of electrons striking the target, the greater the intensity of the x-rays produced.

The mA control on conventional x-ray equipment may only allow for a maximum of 6 to 12 mA to be used, the value being measured across the tube, i.e. between the cathode and the anode. The value required for a specific exposure is usually preset on the panel, this value is usually at, or close to, the maximum mA possible with the equipment for the purpose of minimizing exposure time.

2.6.3 Kilovoltage (kV)

The kV governs the *wavelength* or *quality* of x-rays produced which practically governs *penetrating power*. When the kV is increased, the speed of the electron flow from the cathode to the anode is increased. Therefore, when the electrons strike the target, the kinetic energy is increased, which results in a reduction of wavelength.

An increase in kV, i.e. a shortening of wavelength, has an adverse affect on the contrast and definition of a radiographic image. Certain standard specifications, e.g. BS 2910 : 1986 : *The radiographic examination of fusion welded circumferential butt joints in steel*, state maximum kV values for this reason.

The kV meters on the control panels for conventional x-ray equipment are *peak* kV values measured across the tube, i.e. between the cathode and the anode. The maximum kV which can be used is primarily governed by the tubehead; typical maximum values are 200 kV, 250 kV and 300 kV. The value required for a specific exposure is usually preset on the panel.

2.7 Comparison of x and gamma rays for industrial radiography

2.7.1 Safety

Using x-ray machines is normally safer than using gamma sources because x-ray machines may be switched off like a light bulb, whereas there is a constant emission of radiation with a gamma source. Gamma sources must always be returned to their shielding containers when not in use.

2.7.2 Quality of radiographic images

Assuming variables such as test material thickness, film type etc. remains constant, x-rays produced by conventional x-ray equipment, say up to 300 kV, produce better quality radiographic images than Ir192 or Co60 isotopes, because these x-rays have longer wavelengths than the gamma sources.

Ytterbium 169 (Yb169) may produce radiographs comparable to those produced by using x-rays.

2.7.3 Handling

Gamma sources are easier to handle in comparison with bulky and fragile x-ray equipment. The size also allows for gamma sources to be used in difficult and inaccessible areas for x-ray machines, e.g. on pipe racks.

2.7.4 Cost

Gamma sources and containers are much cheaper than x-ray equipment.

2.7.5 Versatility

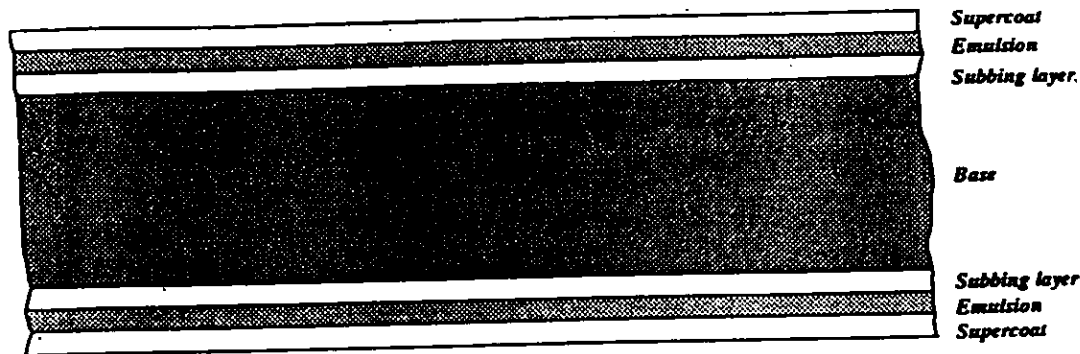
The intensity and wavelengths of x-rays can be adjusted from the x-ray control panel. The intensity and wavelengths of gamma radiation cannot be adjusted, although the intensity (activity) reduces with time—see half-lives.

Certain gamma sources have a very high penetrating power which enables them to be used on very thick material, e.g. 150 mm steel. Most conventional x-ray machines will not penetrate more than 50 mm of steel although there are huge x-ray machines, e.g. the *linear accelerator* and the *betatron* which can produce radiation of a wavelength which can penetrate as much as, and usually more than, gamma radiation.

3 RADIOGRAPHIC FILM

3.1 The make-up of a radiographic film

Radiographic film is usually made up of seven layers: a central base layer and three coatings on either side consisting of a subbing layer, emulsion and supercoat.



Base

The physical characteristics of emulsion do not allow it to be used by itself without support, therefore it is applied to a substrate known as the base. The base must be transparent¹, chemically inert and must not be susceptible to expansion and contraction. Glass is an ideal substrate to meet these requirements, but for applications where the objects to be radiographed are curved, e.g. on pipes, it is necessary for a flexible base to be used. Polyester and cellulose triacetate, although not quite as stable as glass, are widely employed for such applications.

Subbing layer (substratum)

The subbing layers adhere the emulsion to the base; the material employed for this is gelatine plus a base solvent.

Emulsion

The layers of primary importance are the two emulsion layers. These layers consist of millions of silver halide crystals—usually silver bromide; the sizes of the crystals are usually between 0.1 and 1.0 micrometres (μm) and are suspended in a gelatine binding medium.

Film emulsion is produced by mixing solutions of silver nitrate and salts, such as potassium bromide, with a solution of gelatine. The rate and temperature of mixing governs the grain size; rapid mixing at low temperature produces the finest grain structure, whereas slow mixing at high temperature produces emulsions with larger grains. When large grain structures are required, to produce a fast emulsion, some silver iodide is usually included in the formula.

The sizes of these crystals and the distribution, effect the final radiographic quality/appearance; the larger the crystal size the greater the sensitivity to radiation. Various shapes of crystals exist, but these shapes have virtually no effect on the final image.

The reason for two layers of emulsion is to give a faster film speed, i.e. the radiographs can be produced quicker, and higher radiographic contrast.

Supercoat (anti-abrasion layer)

Radiographic emulsion is susceptible to mechanical and chemical damage, so to prevent, or at least reduce this, the emulsion is coated with a layer of hardened gelatine.

Although the supercoat offers some protection against chemical attack, e.g. oil from the skin during handling, it must allow for chemical reactions to take place in the processing tanks.

¹ In practice the base will not be totally transparent and therefore will possess some photographic density.

3.2 Film types

Radiographic film may be graded in terms of grain size or speed¹:

- Ultra fine grain—exceptional radiographic quality but very slow speed.
- Fine grain—slow speed.
- Medium grain—medium speed.
- Coarse grain—poor radiographic quality but fast speed.

Radiographic films are also divided into two types: *direct-type* or *salt screen type*.

Direct-type films are intended for direct exposure to gamma or x-rays or for exposure using lead intensifying screens. Some of these films may be suitable for use with fluorometallic or salt (fluorescent) intensifying screens.

Salt screen type films are designed to be used exclusively with salt (fluorescent) intensifying screens. They are able to produce radiographs with minimum exposure and are widely used in medical radiography.

3.3 Film speed

A film factor is a number which relates to the speed of a particular film and is obtained from a film's *characteristic curve*; see Appendix C.

The *SCRATA scale* is a scale often used for film factors; the smaller the film factor the faster the film. Film manufacturers may have their own scale which may work in the same or opposite way to the SCRATA scale.

Example to the SCRATA scale:

A film with a factor of 10 will be twice as fast compared to a film with a factor of 20. This means to say of the film with a factor of 20 took four minutes to expose, then the film with a factor of 10 will require two minutes to give the same density.

Types of film with their corresponding SCRATA film factors:

Manufacturer	Name	Speed	Grain	Film Factor
Agfa Gevaert Dupont	RCF NDT 91	Fast Fast	Coarse Coarse	
Dupont Kodak Kodak Agfa Gevaert	NDT 75 CX AX D7	Medium Medium Medium Medium	Fine Fine Fine Fine	20 25 30 35
Dupont Agfa Gevaert Kodak	NDT 55 D4 MX	Slow Slow Slow	Very fine Very fine Very fine	80 95 120
Agfa Gevaert	D2	Very slow	Ultra fine	200

¹ The terminology used for grain size and speed can be misleading. The terms used are usually relative, e.g. a fine grain film may be considered to be fast or slow depending on what it is being compared against.

4 INTENSIFYING SCREENS

4.1 General

A radiographic film is normally sandwiched between two intensifying screens when exposed to x-rays or gamma rays. Intensifying screens have an extra photographic effect on the emulsion thereby reducing the exposure needed to attain the required density.

There are three main types of intensifying screens:

1. Lead screens¹.
2. Fluorescent (salt) screens.
3. Fluorometallic screens.

Close contact between screens and film is essential in order to obtain sharp images. Screens must be kept free from dust and scratches, if this is not done they may be seen on the radiographic image—especially in the case of fluorometallic and fluorescent screens.

4.2 Lead screens

Lead screens consist of a thin lead foil of uniform thickness, usually stuck onto a thin base card in the case of reusable screens, or stuck onto a thin sheet of paper when used with pre-packed film.

Lead screens intensify the image by emitting beta radiation (electrons) when struck by x-rays or gamma rays of sufficient energy. The intensification action is only achieved with x-rays above approximately 120 kV and gamma rays above similar energy levels.

Lead screens will also improve the radiographic image by partially filtering out scatter radiation².

Two lead screens are used; the thickness of the front screen must be matched to the wavelength of radiation being used, so that it will pass the primary radiation while stopping as much of the secondary radiation as possible.

The screens are usually between 0.02 mm and 0.15 mm thick and are commonly both the same thickness, e.g. 0.125 mm; this avoids the problem of accidentally loading a cassette with the screens the wrong way round!

The rear screen cuts down the effect of back scattered radiation.

Lead screens are pliable and should be handled with care if buckling is to be avoided. If the lead screens are to be used more than once, e.g. in *cassettes* as opposed to *roll film* or *pre-packed film*, they become dusty and should be frequently dusted with a fine brush. If screens become too dirty or splashed with liquid, they may be cleaned with cotton wool dampened with a weak detergent solution. When the screens become too scratched or dirty causing the radiographic quality to be impaired, they should be replaced by new screens.

4.3 Fluorescent (salt) screens

Fluorescent screens are made up from micro crystals of a suitable metallic salt, usually calcium tungstate, applied to a supporting thin base card.

These screens, when subjected to x-rays or gamma rays, emit light radiation to which the film is sensitive. This light radiation is in direct proportion to the received radiation and results in a large increase of effective radiation.

¹ Other metallic screens exist for less common applications.

² Scatter radiation has a longer wavelength than the primary beam from which it is derived and is therefore less penetrating; see also Appendix B.

There are two types of fluorescent screen:

1. High definition (fine grain) screens
2. High speed or rapid screens

The intensification action of high speed screens is at least twice that of the high definition screens.

A radiograph obtained using fluorescent screens will have lower definition compared to a radiograph taken using lead screens or no screens, and the image produced has a grainy appearance due to the screens salt grains.

Because of the resulting loss of image quality, fluorescent screens are only used where essential, to avoid excessively long exposure times, e.g. on thick walled specimens.

4.4 Fluorometallic screens

Fluorometallic screens are a combination of a salt screen and a lead screen; they are made up of from a base card, a lead layer, a salt layer (calcium tungstate) and a thin protective layer.

There is more than one type of fluorometallic screen:

- Type 1—for x-rays up to 300 kV.
- Type 2—for x-rays 300-1000 kV, Ir 192.
- Type 3—for Co60.

Providing the correct type of fluorometallic screen and film are used with the range of radiation being used, substantial reductions in exposure time or kV can be achieved. Because the lead layer will partially filter out scatter radiation, the image produced on the radiograph will be better than one obtained using fluorescent screens, but the image will still retain a grainy appearance due to the salt crystals.

These screens are not commonly used due to high cost. Their application is similar to those applications where fluorescent screens may be used, i.e. on thick walled specimens.

4.5 Comparison of intensifying screens

Screen type	Order of image quality	Order of speed	Intensification factor ¹	How intensification is achieved
Lead	1	3	2-3	Beta particles and characteristic x-rays
Fluorescent	4	1	8-15	Light radiation
Fluorometallic	3	2	5-10	Light radiation
None	2	4	N/A	N/A

¹ The intensification factor relates to the reduction in exposure time, e.g. an intensification factor of 3 will reduce exposure from say six minutes to two minutes.

5 IMAGE FORMATION

When radiation passes through an object it is differentially absorbed depending upon the thickness and any differing material densities. The radiation finally emerging at the film side of the object will largely determine the final characteristics of the radiograph.

The portions of radiographic film which receive sufficient quantities of actinic radiation¹ undergo minute changes. These changes are so small they are invisible to the naked eye and also invisible when using conventional microscopes; this hidden image is known as the *latent image*. The latent image can be defined as the *hidden image* on a radiographic film after exposure to actinic radiation but before development.

Therefore, radiation alone does not convert a radiographic film into a visible readable image. The sequence of processes to attain a radiographic image are as follows:

1. The silver halide crystals which have absorbed a sufficient quantity of radiation are partially converted into metallic silver—this is the latent image.
2. The affected crystals are then essentially *amplified* by the developer; the developer completely converts the affected crystals into metallic silver.
3. The radiograph attains its final appearance by *fixation*; the fixer removes the unexposed and therefore undeveloped crystals.

6 FILM PROCESSING

6.1 General

Film processing may be carried out manually or by using automatic film processors.

Manual film processing takes place in a *darkroom* under the illumination of *safelights* which usually consist of ordinary light bulbs behind orange filters. Other colours for filters exist, but the colour chosen must emit light of a wavelength which does not detrimentally affect the emulsion.

The darkroom should preferably be divided into two sides, a dry side for loading and unloading of cassettes and a wet side for processing; this is so the films are not splashed prior to development. The wet side of the darkroom will usually have five tanks arranged in the following sequence:

1. Developer tank.
2. Stopbath or rinse tank.
3. Fixer tank.
4. Final wash tank.
5. Wetting agent tank.

When the exposed film has been unloaded from its cassette, it is placed into a *frame*, or *spiral* if its a long film, and placed into the developer.

6.2 Developer

Developer is usually supplied as a liquid concentrate and is to be diluted with water at a ratio governed by the manufacturers instructions, e.g. 1 part developer to 4 parts water.

Developer temperature should be in accordance with the manufacturers recommendations or specification, but is typically $20^{\circ}\pm 1^{\circ}\text{C}$. Development time is again dependant upon the manufacturers recommendations or specification; for manual processing developing time is typically between four and five minutes. The time should be taken from when the film hits the developer with a suitable darkroom timer. Once the film is in the developer it is agitated for approximately 20 seconds and then agitated approximately every 45 seconds thereafter. Agitation allows for fresh developer to flow over the film and prevents the possibility of

¹ Actinic radiation, in this context, is that which will affect the film emulsion, i.e. form a latent image.

bromide streaking; agitation also cuts down development time. The frames or spirals should be *tapped* against the tanks to prevent any air bubbles settling on the film which can cause light spots on the finished radiograph.

Developer is made up as follows:

Constituents	Action	Chemicals in common use
Developing agent(s)	Reduces the exposed silver halide grains to metallic silver.	Metol. Hydroquinone. Phenidone.
Accelerator	A chemical which gives an alkaline reaction which speeds up development.	Borax. Sodium carbonate. Sodium hydroxide.
Preservative	Prevents oxidation of the developer.	Sodium sulphate.
Restrainer	Controls the level of development fogging.	Potassium bromide.
Sequestering agent	Prevents the formation of scale.	Sodium hexametaphosphate.

Replenishment

The activity of the developer gradually decreases with use and age. Replenishment ensures that the activity of the developer and the developing time required remains constant throughout the useful life of the developer. When approximately 1 m² of film has been developed, about 400 ml (2 cups) of replenisher needs to be added. After continuous replenishment the quality of the image will be affected and the developer will have to be changed. A common guide for the remixing time is when the replenisher added exceeds twice the volume of the original developer.

6.3 Stopbath

The stopbath may be:

- An acid stopbath.
- A water spray rinse.
- A fresh water tank.

The most efficient type of stopbath is an acid stopbath which is typically made up of 2% glacial acetic acid in water. This stops the reaction of the developer, due to the developer being an alkali and the stopbath an acid.

Films should be placed and agitated in the stopbath/rinse tank for at least 10 seconds; if this is not done properly, the fixer will soon become neutralised.

6.4 Fixer

Fixer is supplied as a liquid concentrate and is to be diluted with water, usually at a ratio of 1 part fixer to 3 or 4 parts water (follow manufacturers instructions); a *hardening agent* is also added.

Fixation is the process which removes the undeveloped silver halide crystals and *fixes* the remaining developed crystals, thereby producing radiographs of a diagnostic (readable) quality.

The fixer contains chemicals, e.g. ammonium or sodium thiosulphate, which convert the unwanted unexposed, and therefore undeveloped, halides into water soluble compounds; they are then readily dissolved or removed at the final wash stage.

The films must be agitated in the fixer, failing to do so may result in light spots on the film. The fixing time is twice the time it takes for the image to clear, e.g. if the milky image disappears in 3 minutes, after looking under the illumination of the safe lights, the films are returned to the fixing tank for another 3 minutes, i.e. total fixing time 6 minutes. When the fixer becomes exhausted—guideline: when the fixing time is over 10 minutes—the fixer should be replaced; fixers are not usually replenished. The exhausted fixer is retained because silver may be reclaimed via electrolysis methods.

6.5 Final wash

Films should be washed preferably in a tank with constant running water, for at least 20 minutes. This removes any soluble silver compounds left behind in the emulsion after fixing and removes the fixer which is an acid. Yellow fog appears on films which have not been sufficiently washed.

6.6 Wetting agent

Wetting agent reduces the surface tension of the water and results in even drying of the film; this prevents black spots or streaks. Wetting agents are supplied as a liquid concentrate and is to be diluted with water at a ratio of approximately 1 part wetting agent to 4000 parts of water.

Films are only dipped in and out of the wetting agent.

6.7 Drying the film

Initially excess water is removed from the films with a *squeegee* and then placed in either a drying cabinet, other specially designed drying apparatus or a dust free drying room. Care must be taken not to allow drops of water to fall onto the drying films, as this will cause black marks.

The drying time will depend on the temperature, air circulation and the relative humidity of the warm air. Typical drying times are 15 minutes in a drying cabinet, 45 minutes in a drying room.

7 RADIOGRAPHIC QUALITY

7.1 General

Radiographic quality can be discussed using three main terms:

1. **Density**—The density of a radiograph relates its degree of blackness.
2. **Contrast**—Radiographic contrast is the degree of difference between density fields on a radiograph.
3. **Definition**—Radiographic definition is the degree of sharpness at the boundaries of density fields.

A fourth term widely used is *sensitivity*. Sensitivity is a term used to give an indication of overall radiographic quality.

There are two qualities of a radiograph usually measured: density and sensitivity. Density is measured using a *densitometer* and sensitivity is measured using an *image quality indicator (I.Q.I.)*.

Sensitivity measurements give an overall guide as to the radiographic technique's ability to detect fine defects. Sensitivity is affected directly by the contrast and definition, i.e. if either of these qualities are lacking then the sensitivity is lacking.

7.2 Density

7.2.1 General

The density of a radiograph relates its degree of blackness.

A high density or dark area absorbs more light than a low density or light area. The greater the amount of black metallic silver grains present in an area on a radiograph, the more light is absorbed and the denser the area appears.

More radiation passes through the thinner sections of a specimen, e.g. areas where cracks or lack of fusion are present, therefore these areas will eventually show up on the radiograph as dense areas.

7.2.2 Measuring density

Density on a processed radiograph is measured using an instrument called a *densitometer*, this compares the *incident light* with the *transmitted light* and expresses the result as a logarithmic ratio. Incident light is light from the viewer, transmitted light is light transmitted through a film when the film is on the viewer¹.

$$\text{Density} = \text{Log}_{10} \frac{\text{incident light}}{\text{transmitted light}}$$

If the incident light was 316 times greater than the transmitted light:

$$\text{Density} = \text{Log}_{10} \frac{316}{1}$$

$$\text{Density} = \text{Log}_{10} 316$$

$$\text{Density} = 2.5$$

Note: If the transmitted light was 1/10th of incident light $D = 1.0$, if it was 1/100th $D = 2.0$, 1/1000th $D = 3.0$ etc..

Before use, densitometers should be calibrated using a calibrated *density strip*—a strip of film containing known densities—on the same viewer which is to be used for interpreting the radiograph.

The minimum density in the area of interest, i.e. the weld, required by specifications is typically between 1.5 and 2.5. However, this is not always practical to determine when the area of interest has many thickness changes and therefore density changes—as is the case with certain types of m.m.a. welds. In this situation the specification may specify that the density is to be measured immediately adjacent to the weld reinforcement.

The maximum density stated in a specification will typically be 3.0 or 3.5.

7.2.3 Lack of density—causes

- Under exposure to radiation.
- Insufficient development time.
- Developer temperature too low.
- Exhausted developer.
- Incorrect developer.
- Solution of developer too weak.

¹ The viewer must be capable of white light intensities suitable for viewing radiographs up to the maximum permissible densities.

7.2.4 Excessive density—causes

- Over exposure to radiation.
- Excessive development time.
- Developer temperature too high.
- Incorrect developer.
- Solution of developer too strong.

7.3 Radiographic contrast

7.3.1 General

Radiographic contrast is the degree of difference between density fields on a radiograph.

When a radiograph contains only blacks and whites and no intermediate tones the contrast is *high*; when only tones of a similar density exist the contrast is *low*; the optimum contrast may lie between these two extremes, it depends on the aim of the radiographic technique.

If an application specification is not permitting any detected defects in the weld whatsoever, then the contrast should ideally be as high as possible, i.e. high contrast is ideal for detecting defects.

If however, an application specification permitted certain defects, depending on the defects through thickness dimensions, as well as length and/or width, then it would be necessary to have a range of tones on the radiographs¹ so that the through thickness depth of the defects and the height of weld reinforcements can be assessed.

Therefore, to gain more information about the through thickness dimensions of any defects and the weld itself, we need to have intermediate tones, i.e. greys in addition to black and whites.

Note: We are assuming that there are thickness changes or material density changes present in order to give us density changes.

The following chart shows the criteria which affect radiographic contrast:

¹ If a radiograph shows a wide range of tones it is said to have *wide latitude*.

7.3.2 Measuring radiographic contrast

Radiographic contrast is not usually measured exclusively; it is normally assessed subjectively, but could be measured by the use of a *step wedge* type I.Q.I..

A wire type I.Q.I. — used to measure sensitivity — primarily gives information about the radiographic contrast, but the degree of definition also governs the result.

7.3.3 Insufficient contrast — causes

- Radiation wavelength too short, i.e. kV/penetrating power too high.
- Over exposure to radiation, compensated for by shortened development time.
- Prolonged development in too cold a developer or exhausted developer.
- Unsuitable or wrongly mixed developer.
- Insufficient fixation.
- Fog; see also Section 7.5.

7.3.4 Excessive contrast — causes

- Radiation wavelength too long — kV/penetrating power too low.
- Incorrect developer.
- Wrongly mixed developer.
- Under exposure, compensated for by a prolonged developer.

7.4 Definition

7.4.1 General

Radiographic definition is the degree of sharpness at the boundaries of density fields.

There are many factors that govern the final definition on a radiograph, including the geometry of the set-up during exposure and the film type used. Perfect definition can never be obtained due to the existence of *penumbra* and the films *inherent unsharpness*.

7.4.2 Measuring radiographic definition

Radiographic definition is not usually measured exclusively; it is normally assessed subjectively, but could be measured by the use of a *duplex* type I.Q.I..

A duplex type I.Q.I. is a type III I.Q.I. to BS 3971 — *Image quality indicators*, also referred to as a *CERL type B*. It consists of pairs of parallel platinum or tungsten wires of decreasing thickness, the thickness of the pairs usually being the same as the gap between them. If a pair of parallel wires blend into one on the radiographic image it will be due to the poor definition. The largest pair of wires, the image of which has just merged from that of two separate wires into the single form, is taken as the criterion of discernability. The total image unsharpness, U_t is given by:

$$U_t(mm) = d + a$$

where:

d is the width of the wire

a is the spacing between the two wires

Note: Type III I.Q.I.s are placed in the centre of the film adjacent to the weld.

7.4.3 Poor definition—causes

- Object to film distance (o.f.d.) too great.
- Radiation source to film distance too short.
- Dimensions of focal spot or gamma source too large.
- KV too high.
- Vibration/movement during exposure.
- Poor contact between film and screens.
- Salt screens.
- Coarse grained film.
- Fog; see also Section 7.5.

7.4.4 Inherent (film) unsharpness

Inherent unsharpness is the unsharpness on a radiograph caused by stray electrons transmitted from exposed crystals which have affected adjacent crystals. Inherent unsharpness always exists, its magnitude depending on grain size, grain distribution and radiation energy used; it increases with a reduction in wavelength.

7.4.5 Geometric unsharpness

Geometric unsharpness or *penumbra* is the unsharpness on a radiograph caused by the geometry of the radiation beam in relation to the object being radiographed and the film. Penumbra always exists and borders all density fields.

The dimensions of the focal spot or gamma source, object to film distance (o.f.d.) and focal spot to film distance (f.f.d.)¹ all affect penumbra.

To minimise penumbra we must adhere to the following conditions:

- The source or focal spot should be as small as possible.
- O.f.d. should be as small as possible.
- F.f.d./s.f.d. should be as long as practicable.

¹ Source to film distance (s.f.d.) if using gamma radiation.

Penumbra size can be calculated by the following formula:

$$\text{Penumbra} = \frac{\text{size of source} \times \text{o.f.d.}}{\text{f.f.d.} - \text{o.f.d.}}$$

The maximum penumbra allowed on radiographs is specified in certain standards. In contractual situations where the standards do not quote maximum penumbra values, they may be agreed with the client; a maximum penumbra of 0.25 mm is often used.

The BS 2910 does not quote a maximum penumbra value, but *recommends* that the penumbra levels do not exceed the maximum levels specified for inherent unsharpness. The minimum f.f.d./s.f.d. charts in BS 2910 are primarily based on penumbra considerations, i.e. if these charts are being adhered to the penumbra is considered to be acceptable.

7.5 Fog

7.5.1 General

Fog is unwanted density on a radiograph and may be sub-divided into the following terms:

- Grey fog—often simply termed fog.
- Yellow fog.
- Dichroic fog—greenish colour by reflected light, pink via transmitted light.
- Mottled fog.

7.5.2 Causes of fog

7.5.2.1 Grey fog

- Accidental exposure to actinic radiation—light, x-rays, gamma rays. When fog is caused by light leaks, e.g. because of a faulty cassette, it is often termed *light fog*.
- Scatter.
- Unsuitable darkroom lighting, e.g. wrong safelights, white light entering darkroom.
- Bad film storage.

7.5.2.2 Yellow fog

- Insufficient final wash.
- Exhausted fixer.
- Prolonged development in badly oxidized developer.

7.5.2.3 Dichroic fog

- Prolonged development in exhausted developing bath.
- Film stuck to another film in fixer.
- Developing tank contaminated with fixer.

7.5.2.4 Mottled fog

- Film badly stored, e.g. in damp surroundings.
- Film out of date.

7.6 Artifacts

7.6.1 General

An artifact is a spurious indication on the radiographic image, e.g. a fault in or on the film usually caused by mishandling or incorrect developing. An artifact may appear to be a defect in the weld or parent material; an artifact may also mask a fault in the weld, therefore, it is essential that artifacts should be avoided.

7.6.2 Static discharge

Static discharge marks may occur when the film is pulled quickly from between the intensifying screens in a dry atmosphere. The appearance on the radiograph is usually *lightning* like, but it may also be mottled.

7.6.3 Reticulation

Reticulation is a *net* like structure appearing in the emulsion due to rupture caused by excessive temperature differences between the processing tanks. It is a rare artifact nowadays to to the flexible/plastic nature of modern day emulsions.

7.6.4 Diffraction mottle

Diffraction mottle may occur in a weld area on a radiographic image because of the grain structure and grain orientation of certain materials matching the wavelength of the radiation in a certain way. Austenitic stainless steels and aluminium welds are particularly susceptible.

Diffraction mottle has the appearance of fine porosity throughout the weld area. It may be reduced or eliminated by changing the wavelength of radiation, i.e. increasing kV¹, or by changing the radiation angle by approximately 5°.

7.6.5 Causes of other artifacts

7.6.5.1 Light patches

- Film was not agitated/tapped during development or fixation.
- Film insufficiently rinsed after development.
- Drops of fixer fell onto film prior to development.
- Mechanical damage to emulsion.
- Impurities between screen and film.

7.6.5.2 Dark patches, lines or streaks

- Drops of developer fallen onto film prior to development.
- Drops of water fallen onto film prior to development.
- Mechanical damage to emulsion after exposure.
- Slow and uneven drying of film, i.e. when there are still droplets of water on the film.
- Uneven drying.
- Scratches on lead screens.
- Bending of film after exposure (usually between two fingers causes dark crescent shaped marks).

7.6.5.3 Whitish deposit

- Water used to make up processing solutions too hard.

¹ Diffraction mottle often increases with a reduction in kV!

7.7 Sensitivity

7.7.1 General

The term *sensitivity*, when used in its general sense, is an overall assessment of quality which relates to the radiographic technique's ability to detect fine defects on a radiograph.

The sensitivity associated with a radiograph is directly affected by the radiographic contrast and definition, therefore all those factors which affect contrast and definition will also affect the sensitivity.

7.7.2 Measuring sensitivity

Sensitivity is measured by the use of *image quality indicators (I.Q.I.s)*, also known as *penetrameters*. There are various types of I.Q.I.; the type commonly used consists of seven thin wires within a plastic packaging. The wires are placed transversely across the weld area being examined during exposure. The sensitivity on the resultant radiograph is then given a numerical value by dividing the thickness of the smallest wire visible on the radiograph by the thickness of the specimen in the area being examined; this is then multiplied by 100 in order to express the result as a percentage of the specimen thickness¹.

$$\text{Sensitivity \%} = \frac{\text{thickness of thinnest wire visible}}{\text{thickness of specimen}} \times 100$$

The lower the figure obtained, the higher the sensitivity. It must be noted however, that the obtained I.Q.I. sensitivity value does not directly relate to the minimum thickness change or defect size detectable by the radiographic technique used.

BS 3971—*Image quality indicators* is a standard which specifies three types of I.Q.I.:

- Type I — wire type.
- Type II — step wedge/hole type.
- Type III — duplex wire type for exclusively measuring definition; see Section 7.4.2.

Step wedge/hole type I.Q.I.s are placed adjacent to the weld in the centre of the film. The sensitivity is assessed in the same way as for wire types except you use the hole diameter instead of a wire thickness.

With the exception of duplex wires, I.Q.I.s are made of the same material² as the specimen being examined and are available in a variety of thickness ranges.

Technically, the best position to place an I.Q.I. is on the *source* side of the specimen, but for practical reasons I.Q.I.(s) are often placed on the *film* side, i.e. between the film and the specimen. It may also be stated that they must be positioned in the area where the worst sensitivity is expected. A specification relating to radiographic testing large diameter pipe welds may state:

"For a panoramic exposure at least one I.Q.I. must be present³, placed at the 6 o'clock position". Reason: because this area is more susceptible to back scatter from the ground.

¹ Sometimes the minimum number of wires which have to be visible on the radiograph is specified instead.

² Although it is desirable for the IQI and the specimen to be of the same material, it is not always possible or practicable to accomplish due to lack of availability. For test specimens made from alloyed elements, the IQI material chosen should have similar radiation absorption/transmission properties to the test specimen.

³ BS 2910 calls for four IQI's placed at the 3, 6, 9, and 12 o'clock positions.

"For a multiple exposure technique two I.Q.I.s must be used, one at each end of the film within 25 mm of the diagnostic film length, with the thinnest wire facing towards the outside". Reason: the outside/end of a film on a multiple exposure shot is the least sensitive area due to *fade off*.

7.7.3 Specific sensitivity terms

There are many specific terms relating to sensitivity which may be encountered; the following terms are in accordance with BS 3683—*Terms used in non-destructive testing : Part 3—Radiological flaw detection*:

Contrast sensitivity

The density difference on a radiograph after processing, produced by a small change in specimen thickness.

Note: It is usually expressed as a percentage of the total specimen thickness.

Defect detection sensitivity

In a radiograph, the minimum dimension of a specified defect that can be discerned, measured in the direction of the primary radiation beam and usually expressed as a percentage of the specimen thickness.

Flaw sensitivity

The minimum flaw size detectable under specified conditions usually expressed as a percentage of the specimen thickness. (See also *defect detection sensitivity*).

Image quality indicator sensitivity

The dimension in the direction of the radiation of the thinnest step-with-hole or wire that can be clearly identified, expressed as a percentage of the thickness of the material under examination.

Note: The duplex-wire image quality indicator is based on a different principle and gives a measure of unsharpness only.

Thickness sensitivity

The smallest change in thickness which can be detected by radiography, usually expressed as a percentage of the specimen thickness.

8 RADIOGRAPHIC TECHNIQUES

8.1 General

Radiographic techniques for welds on steel are listed in BS 2910—*Radiographic examination of fusion welded circumferential butt joints in steel* and BS 2600—*Radiographic examination of fusion welded butt joints in steel*.

The radiographic examination of a plate weld would result in a *single wall, single image* technique being used; however, there are essentially four ways to radiograph a girth/pipe weld:

1. Single wall, single image (SWSI)—film inside, source outside.
2. Single wall, single image (SWSI)—film outside, source inside (internal exposure, usually full panoramic).
3. Double wall, single image (DWSI)—film outside, source outside (external exposure).
4. Double wall, double image (DWDI)—film outside, source outside (elliptical exposure).

The panoramic technique is usually the preferred technique if the equipment is available, access permits and the minimum f.f.d. requirements are met. This is due to the fact that the entire weld can be examined in one exposure, and good sensitivity can be achieved because of a lower level of scatter and kV in comparison with a double walled exposure.

8.2 SWSI: source outside, film inside

For standard exposures, the radiation beam is positioned at normal incidence to the weld face and film passing through the centre of the weld.

This technique is primarily intended for 100 mm diameter pipe welds and above, where access to the internal weld area permits. The main disadvantages of this technique are the number of exposures required due to a large amount of fade off, and the practical aspects of positioning the radiation source at sufficient f.f.d. when dealing with fabrications *in situ*. It is a technique more suited to large diameter pipes, vessels and tanks where the curvature is closer to a flat plate and therefore has a reduced effect on the amount of fade off.

The required minimum number of exposures to cover the full circumference of the weld depends on the wall thickness, pipe diameter and f.f.d./s.f.d.; see table in BS 2910.

8.3 SWSI: (panoramic) source inside, film outside

For standard exposures, the radiation beam is positioned at normal incidence to the weld face and film passing through the centre of the weld, with equal f.f.d./s.f.d. around the circumference. This technique cannot be used if the minimum f.f.d./s.f.d. requirements cannot be met.

8.4 DWSI

This technique is commonly applied to all welds where the use of a panoramic technique is not possible or practicable, e.g. on small diameter pipe welds.

For standard exposures on any diameter of pipe weld, the radiation beam is positioned at approximately 85° to the weld face and film. With this technique the radiation beam cannot be positioned at normal incidence to the weld portion being examined because the weld on the radiation source side will superimpose over the film side weld resulting in a reshootable radiograph. This problem mainly applies when using x-ray tubes; the x-ray tube must be moved approximately 60 mm to the side of the weld, so the central line of the x-ray beam shoots past the tube side weld resulting in a diagnostic image of the film side weld. Care must also be taken to ensure that the number tape on the source side does not interfere with the image, i.e. shoot through from the opposite side of the weld to that which the number tape is positioned.

The required minimum number of exposures to cover the full circumference of the weld depends on the wall thickness, pipe diameter and f.f.d.; see table in BS 2910.

8.5 DWDI

This technique is only applied to welds on pipe or fittings 90 mm diameter or below.

The film cassettes are not bent around the pipe circumference unlike with the other techniques; flat cassettes are used which are usually offset to the weld to record an elliptical image, purposely produced by offsetting the focal spot at least one fifth of the f.f.d.. From the elliptical image of the weld, the tube side weld is interpreted as well as the film side weld.

A minimum of three exposures are usually required, offset by 120° to each other; this results in a total of six interpretable areas on the radiograph which should cover the full circumference of the weld.

Note: On small bore pipework, it is sometimes permitted by specification or client for the radiation to pass through the centre of the weld at normal incidence to the pipe; this will produce a radiograph with the tube side weld superimposed over the film side weld.

8.6 Sandwich technique

The *sandwich* technique is a radiographic technique sometimes used in order to save time. It may be used on components where there are substantial thickness differences causing the density on a single radiograph to be out of specification on either the thicker side, the thinner side or both. Rather than carry out two separate shots at different exposures for each weld or position, cassettes may be loaded with two films. Two radiographs will therefore be produced—one for the thick side and the other for the thinner side—but they will have been produced in a single exposure.

The films are usually of different speeds, e.g. a fine grained film loaded with a very fine grained film, however, the same effect will be produced by placing a lead screen, thicker than usual, between two films of the same speed.

8.7 Parallax technique

The *parallax* radiographic technique¹ may be used to determine the depth of defects below the surface of a component; this may be useful to know for repair purposes. It is a technique more applicable to thick specimens, e.g. over 50 mm, but is rarely used because ultrasonic testing can usually give the same information quicker and at a lower cost.

The technique is used after a defect has already been detected by conventional methods. The procedure involves the placement of a lead marker on the source side of a specimen's surface close to the plan view location of the defect. Two exposures are made, each at half the normal exposure, and offset to each other in order to produce a double image of the lead marker and defect.

The following criteria are used to calculate² the distance of the defect from the film:

- a. Gap between defect images.
- b. Gap between lead marker images.
- c. $F.f.d./s.f.d.$
- d. Specimen thickness.
- e. Dimension of shift between source of radiation.

9 DETERMINATION OF EXPOSURE

9.1 General

Many factors govern the final quality³ of a radiographic image; all these factors must be considered and controlled in order to meet with a specifications requirements.

The *time* to use for an exposure is only one factor to consider for an exposure, but it is this factor which changes most often. Gamma exposure times are usually calculated from special slide rules, usually referred to as *gamma exposure calculators*, these take into consideration the following:

- a. Film density to be achieved.
- b. Source type.
- c. Activity of source.
- d. Film speed.
- e. Source to film distance.
- f. Material type.
- g. Material thickness.

1 The parallax technique is sometimes referred to as the *tube shift method* when an x-ray tube is used.

2 A formula or a special graph may be used to determine defect depth.

3 *Quality* is referring to density, contrast and definition.

When using x-ray equipment, the determination of exposure is less straightforward. This is because the wavelength and intensity of radiation may be adjusted, and different machines produce different quantities and qualities of x-radiation even though they may be operated on the same panel settings. The following methods are used to determine correct exposures when using x-ray equipment:

- a. By reference to previous exposure records.
- b. By trial and error—*test shots*.
- c. A combination of the above.
- d. By using exposure charts.

9.2 Considerations for exposures

9.2.1 Wavelength of radiation

The wavelength of radiation used will affect the density, contrast and definition of a radiographic image.

X-ray equipment—The lower the kV used to penetrate the specimen, the higher will be the contrast, but enough kV must be used to keep the exposure time reasonable.

Gamma isotopes—Different radioactive isotopes produce different wavelengths of gamma radiation, e.g. Co60 produces shorter wavelength radiation than Ir192 and is therefore more penetrating, but a radiograph produced on the same specimen using Co60 will have lower contrast and definition.

9.2.2 Intensity of radiation and exposure time

The intensity of the radiation reaching the film and exposure time will affect the density of the image¹.

Radiation intensity and exposure time are related. Exposure time is proportional to the intensity of radiation; this relationship is known as the *reciprocity law*:

$$\text{Exposure} = \text{time} \times \text{intensity}$$

X-ray equipment—If you had an exposure of say 4 minutes and 3 mA, then $4 \times 3 = 12$, therefore you would be using 12 mA-mins. You could also use 3 minutes and 4 mA to give you the same amount of exposure because $3 \times 4 = 12$, or 1 minute 12 mA, $1 \times 12 = 12$, or 2 minutes 6 mA, $2 \times 6 = 12$ etc.; all these give you the same amount of exposure.

The higher the mA setting on the control panel, the greater the intensity of radiation produced, and therefore the darker the image will be, unless the time is reduced to compensate.

Gamma isotopes—If you had an exposure of say 5 minutes using an isotope with an activity of 4 curies, then $5 \times 4 = 20$, therefore you would be using 20 Ci-mins.

The higher the *activity* of the isotope used, the greater the intensity of radiation produced, and therefore the darker the image will be, unless the time is reduced to compensate.

9.2.3 X-ray equipment

The intensity of radiation (governed by mA) and quality of radiation (governed by kV) can be affected by the electric circuit of the equipment being used. The kV and mA may be on the same panel setting, but the radiation intensity and wavelengths can vary from one set to another.

¹ Remember that density affects contrast, and contrast affects sensitivity.

Filter types and thicknesses also differ between x-ray tubes. Filters are used to cut out secondary radiation to provide a more homogeneous x-ray beam with lower resultant scatter levels. Filters affect the exposure time, e.g. an x-ray tube with a thick filter will require more exposure than an x-ray tube with a thinner filter.

9.2.4 Type of film

The higher the speed of the film, the denser the image compared to that of a slow film at the same exposure. However, the radiograph's definition for a slow film at the correct exposure will be better than that for a fast film at the correct exposure.

9.2.5 Intensifying screens

Using intensifying screens reduces the exposure required to attain the required density, but fluorescent and fluorometallic screens have an adverse affect on the definition of the radiographic image.

9.2.6 F.f.d./s.f.d

The greater the f.f.d./s.f.d. the smaller the penumbra, therefore the better the radiographic definition. But, x-rays and gamma rays obey the inverse square law. The inverse square law states:

"At twice the distance from the source, the same radiation covers four times the area but the intensity of radiation is four times less. At four times the distance from the source the same radiation covers sixteen times the area but the intensity of the radiation is sixteen times less, etc."

Therefore, with regard to exposure, the greater the f.f.d./s.f.d. the greater the exposure should be to attain a given density.

The inverse square law can be shown mathematically in relation to intensity:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

I = intensity

D = distance

The following formula, based on the inverse square law, can be used to determine new exposures when the f.f.d./s.f.d. changes:

$$\text{New Exposure} = \frac{\text{New Distance}^2 \times \text{Old Exposure}}{\text{Old Distance}^2}$$

9.2.7 Object being radiographed

The radiation absorption and transmission characteristics of a material depends upon its thickness, density and atomic mass. This will primarily govern penetrating power required.

9.2.8 Processing the film

The density, contrast and definition of a radiograph are affected by the type, temperature, agitation and time in the developer. The development process should not be adjusted outside a specifications requirements in order to compensate for incorrect exposures, i.e. to adjust the density of a radiograph, the exposure should be changed; not the developing process.

9.3 Exposure charts

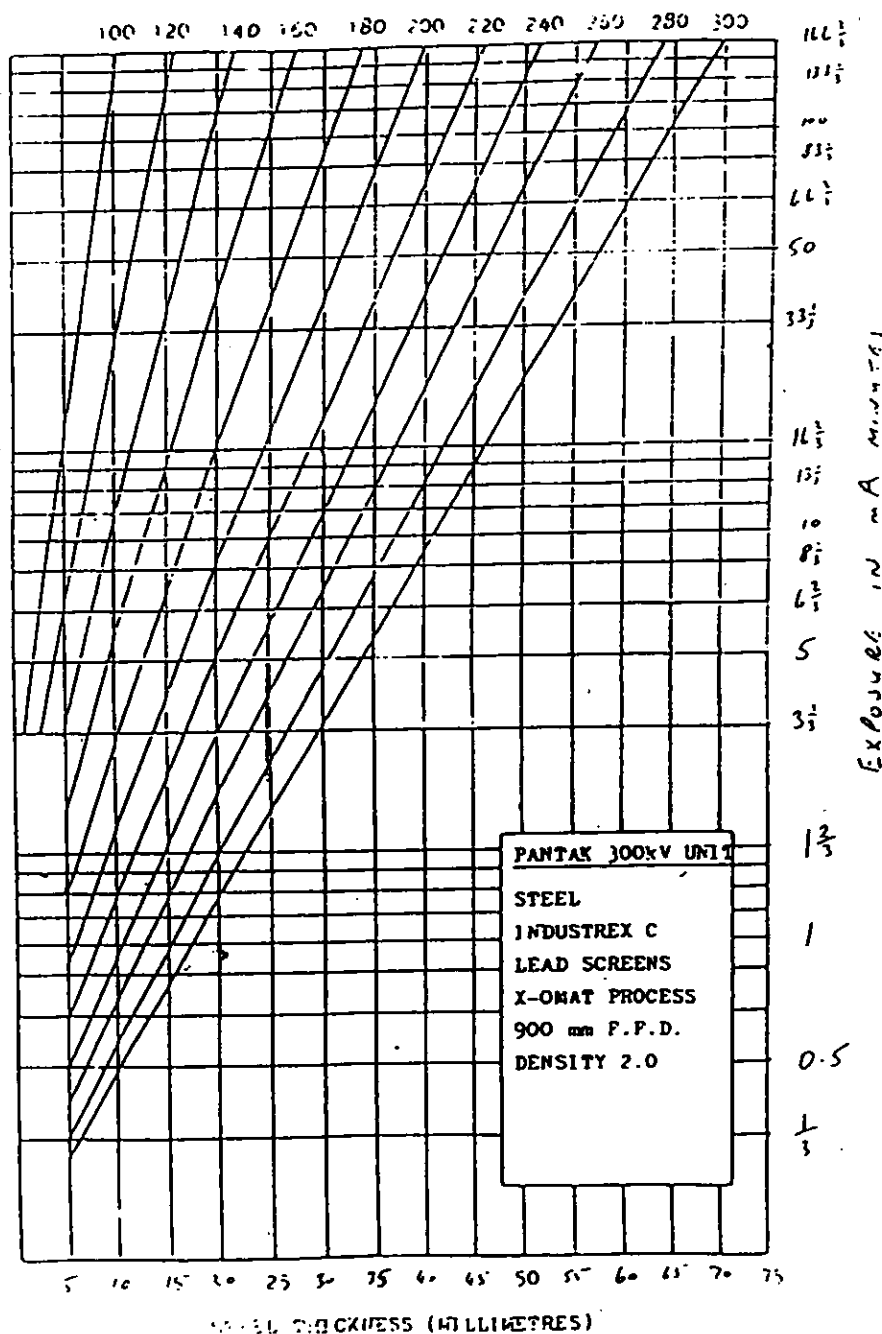
Exposure charts provide the exposure conditions for a given thickness of material using x-ray equipment. An exposure chart will show the exposure to use in mA-min for a chosen specimen thickness and kV in order to attain the density that the chart is based on.

Exposure charts are drawn up from preliminary charts made up from exposures using different kilovoltages on step wedges.

The vertical scale on an exposure chart is logarithmic and the horizontal scale is arithmetic.

Each chart must show the variables to which the chart is applicable to:

- Type of x-ray set.
- Film density.
- Film type.
- Intensifying screens
- Focus to film distance.
- Development conditions.
- Material tested.



9.4 Guideline exposures using x-rays

The following chart shows guideline x-ray exposures on standard wall thickness A.P.I. pipes using fine grain film with lead screens.

Technique (BS 2910)	Dia. (mm)	Time (min)	mA	kV
13 DWDI*	50	2.5	5	200
13 DWSI	100	1.15	5	165
13 DWSI	300	2.5	5	220
13 DWSI	450	4.75	5	230
7 SWSI	450	1.15	5	175
13 DWSI	600	5	5	245
7 SWSI	600	1.75	5	175
13 DWSI	900	5	5	270
7 SWSI	900	3	5	195
13 DWSI	1050	12	5	300
7 SWSI	1050	3.5	5	210
* Focus to film distance = 650 mm.				

APPENDIX B SCATTER

When radiographic exposures are being made, some of the radiation scatters in all directions by the atoms which form the object. This scatter results in an overall *fogging* of the film and reduces the contrast and sharpness of the radiographic image. The thicker the object being radiographed, the greater the amount of scatter.

Furthermore, the ground, a wall, or another object close to the object being radiographed which is struck by the radiation, will partially reflect the rays in the form of *back scatter*; this is also liable to fog the film.

Scatter radiation is less penetrating than primary radiation from which it is derived. Because scatter rays have a relatively long wavelength, they can be intercepted by a sheet of lead; this is one reason for using lead screens, although heavier filters may also be needed if the scatter is heavy.

APPENDIX A DETERMINATION OF FOCAL SPOT SIZE

The focal spot size of x-ray tubes can change over a period of time. To determine the size of the focal spot, e.g. for penumbra calculations, the following procedure may be adopted.

1. Place a lead sheet, approximately 4 mm thick containing a small hole about 0.25 mm diameter, exactly half way between the focal spot and a radiographic film.
2. Expose—the exposure should not be excessive otherwise the image will be blurred. The image on the film will be the size of the focal spot plus twice the diameter of the hole.
3. Calculate the focal spot size by measuring the total diameter of the image and then deduct 2 x hole diameter.

APPENDIX C CHARACTERISTIC CURVES OF FILMS

A characteristic curve is a curve on a graph produced for a particular film which shows the relationship between different exposures applied and the resulting densities.

A characteristic curve will show that the density does not always vary in the same proportion as the applied exposure.

A curve is produced by applying increasing exposures to adjacent areas of a strip of film. After development, the densities are measured with a densitometer and then plotted on a graph against the corresponding exposures. Both the vertical axis (density) and horizontal axis (exposure) are calibrated in a logarithmic scale ($\log_{10}E$); this method is the most practical method for the size and interpretation of a curve. When the points obtained are joined together a curve will be produced.

If characteristic curves of various films were superimposed on one graph, it will be seen that the faster films lie closer to the left vertical axis, because faster films attain density at lower exposures. Therefore, it should be appreciated that it is possible to obtain the relative *film factors* from the characteristic curves of films.

The highest *film contrast* of a given film lies on the *straight line portion* of its characteristic curve, this indicates the density range to work with to attain optimum contrast. Also, the steeper the *gradient* of the straight line portion the higher the film contrast.

APPENDIX D DUTIES OF A RADIOGRAPHIC INTERPRETER

It is the duty of a radiographic interpreter to ensure that all interpretation and any associated actions are carried out in accordance with the relevant specification(s) for the work being carried out.

A radiographic interpreter must have access to the relevant specification(s) and must know where to find and interpret relevant information.

Specific duties when interpreting radiographs of welds are typically as follows:

1. Mask off any unwanted light on the *viewer*.
2. View radiographs under subdued background light.
3. Ensure, as far as is reasonably practicable, each radiograph is correctly identified to the weld it represents.
4. Ensure that the weld locations are identified, e.g. has the correct *number tape* been used.
5. Assess the quality of the radiograph:
 - a. Measure radiographic density.
 - b. Calculate IQI sensitivity—also ensure the IQI's are of the correct type and correctly positioned.
 - c. Assess radiographic contrast; e.g. has gamma been used when only x-radiography is permitted?.
 - d. Assess definition/graininess; e.g. have salt intensifying screens been used when only lead intensifying screens are permitted? Has a fast film been used instead of a slow film?.
 - e. Do artifacts interfere with interpretation?
6. Check the radiograph to determine if any obstruction between the source of radiation and the film interferes with interpretation, e.g. lead numbers.
7. Identify the type of weld if possible—normally already known.
8. Check the parent material on the radiograph for arc strikes, hard stamping, gouges, minimum seam offset etc., when applicable.
9. Check the weld on the radiograph for defects, stating type and region.
10. State action to be taken, e.g. accept the radiograph and weld, reshoot, repair, remove the entire weld, visual check, grind and investigate, MPI check, ultrasonic check.

Other points—always note *suspect* cracks or obvious defects on a reshootable radiograph. It will probably not be necessary to reshoot a reshootable radiograph if the weld is to be removed (cut-out).

APPENDIX E QUALITY ASSURANCE

BS 5750 [ISO 9000 series]—*Quality systems*

BS 4778—*Quality vocabulary*

E.1 Aim of quality assurance

The aim of quality assurance is to improve quality whilst keeping costs to an acceptable level.

The objective of a system used to implement quality assurance, i.e. a *quality system*, is to determine and rectify the root cause(s) of any problems, thereby reducing faults and wastage. This will in turn, improve quality and reduce costs. The emphasis is on prevention rather than detection and cure.

E.2 Benefits of adopting quality assurance

A properly implemented and managed quality system should:

- a. help to ensure that the company focuses on market needs and requirements;
- b. make the company more competitive in the market place due to an increased customer confidence in the company's output, i.e. a product or service that a customer wants—this includes timing;
- c. lead to a reduction of costs due to a reduced number of faults and wastage;
- d. give a measure of performance which will enable any areas for improvement to be identified;
- e. induce a more organized way of thinking which makes management more organized and effective;
- f. provide motivation; motivated employees provide a better working environment in addition to the product or service output benefits.

E.3 What is quality assurance?

The definition for *quality assurance* given in the British Standard for quality vocabulary (BS 4778 : Part 1) is:

'All those planned or systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.'

The quality of a product or service is attained only by working in a controlled manner, following formalised procedures which are designed to eliminate the occurrence of problems.

Quality assurance provides the objective evidence needed to give maximum confidence for quality.

Quality assurance should be considered as a management *tool* when used within an organization (*internal quality assurance*). A supplier who implements and maintains a system for assuring quality, is providing maximum confidence to a purchaser, or potential purchaser, that the supplied product or service attains, or is going to attain, its fitness for purpose.

Different people have different concepts for what is meant by a *quality* product or service, therefore it is very important to be aware of the customers' requirements and/or expectations.

In industrial contract situations, contract documents or purchasing specifications should clearly define a company's requirements for a product or service. The quality of the product or service is deemed to have been achieved when the exact requirements have been met completely and consistently.

E.4 Scope of quality assurance

Quality assurance should encompass all parts of an organization and all phases of an activity,¹ i.e. planning, design, production, maintenance, administration etc.. Collaboration with suppliers and purchasers should also be part of an organization's quality system.

E.5 Inspection vs quality assurance

Quality assurance is not inspection. Inspection is one of the important elements within a system for quality assurance which requires continuing evaluation in the same way as the other elements, e.g. planning, design/specifications, production etc...

Inspection is defined in *BS 4778 : Part 1* as, 'activities such as measuring, examining, testing, gauging one or more characteristics of a product or service and comparing these with specified requirements to determine conformity.'

E.6 Inspection vs quality control

Quality control is defined in *BS 4778 : Part 1* as, 'the operational techniques and activities that are used to fulfil requirements for quality.' This definition can be vague, so modifying the term to be more specific is advantageous, e.g. *manufacturing quality control* is more explanatory.

Quality control is involved with the monitoring of a process and eliminating the causes of any deficient output with any process, or any phase during a contract, which has an effect on quality. The information obtained from inspection, as defined above, is used for quality control.

E.7 Quality control vs quality assurance

The comparison between quality control and quality assurance is more difficult to explain because of different beliefs between experts. Assumptions are also made regarding the applicability of the term *quality control*, e.g. is it referring to *manufacturing quality control* or *company-wide quality control*?

Quality control deals with the actual measurement of quality performance, this performance is compared against what is required, and action is taken on the difference.² Quality control is asking the question, "is the work/action *being* performed correctly?"

Quality control does not reach all elements which affect quality, e.g. quality control will rarely do anything to correct problems relating to management, documentation, training and staff motivation.

Quality assurance applies to all areas which have an affect on quality, and asks the question, "has the work/action *been* performed correctly?"

¹ *Total Quality Management (TQM)* is a concept adopted by some companies which applies quality assurance philosophy to all areas within a company, whether they are deemed to have a direct affect on quality or not.

² This philosophy has been taken from J M Juran

LEVEL 2 - RADIOGRAPHIC TESTING - GENERAL

PAPER No. RT1G2

NAME:

COMPANY:

DATE:

SIGNED:

RESULTS: Gamma.

2-12mm Xb169.

10-50mm IR192.

50mm & greater Co60.

Query if on reports?

1. Calcium tungstate screens used in industrial radiography are usually used to:

- A. improve definition in radiographic images.
- B. improve contrast in radiographic images.
- ☒ C. decrease exposure time.
- D. make films with multi-million volt radiation.

X-ray
Below 120kV no screen
upto 12mm → 150kV max
12-25 → 200kV max.
25-50 → 300kV max.

2. The penetrating ability of an x-ray beam is governed by:

- ☒ A. kilovoltage or wavelength.
- B. time.
- C. milliamperage.
- D. source-to-film distance.

3. The two most common causes for excessively high-density radiographs are:

- A. insufficient washing and overdevelopment.
- B. contaminated fixer and insufficient washing.
- ☒ C. overexposure and contaminated fixer.
- ☒ D. overexposure and overdevelopment.

4-5 min at 20°C

4. When struck by x-rays or gamma rays, lead screens emit:

- A. alpha particles.
- ☒ B. beta particles.
- C. fast neutrons.
- ☒ D. ultraviolet light.

5. The ability to detect a small discontinuity or flaw on a radiograph is called:

- A. radiographic contrast.
- ☒ B. radiographic sensitivity.
- C. radiographic density.
- D. radiographic definition.

6. Movement, geometry and screen contact are three factors that affect radiographic:

- A. contrast.
- ☒ B. unsharpness.
- C. reticulation.
- D. density.

7. The degree of difference between the densities of two areas of a radiograph is called:
- ☒ A. radiographic contrast.
 - B. subject contrast.
 - C. film contrast.
 - D. definition.
8. Which are the axes found on a characteristic curve?
- A. Exposure and contrast
 - B. Density and definition
 - ☒ C. Log relative exposure and density
 - D. Density and contrast
9. If a film is placed in a developer solution and allowed to develop without any agitation:
- A. the radiograph will not show proper contrast.
 - B. it will be impossible to fix the radiograph permanently.
 - ☒ C. there will be a general fogging condition over the entire radiograph.
 - D. bromide streaking may result.
10. When radiographing a part which contains a large crack, the crack will appear on the radiograph as:
- ☒ A. a dark, intermittent or continuous line.
 - B. a light, irregular line.
 - C. either a dark or light line.
 - D. a fogged area on the radiograph.
11. A cobalt-60 source has a half-life of:
- A. 1.2 years.
 - B. 6 months.
 - ☒ C. 5.3 years.
 - D. 75 days.
12. Lead foil in direct contact with x-ray film:
- ☒ A. intensifies the scatter radiation more than the primary radiation.
 - B. decreases the contrast of the radiographic image.
 - ☒ C. intensifies the primary radiation more than the scatter radiation.
 - D. should not be used when gamma rays are emitted by the source of radiation.
13. Radiographic sensitivity, in the context of the minimum detectable flaw size, depends on:
- A. graininess of the film.
 - B. the unsharpness of the flaw image in the film.
 - ☒ C. the contrast of the flaw image on the film.
 - D. all three of the above.
14. In order to decrease geometric unsharpness:
- ☒ A. radiation should proceed from as small a focal spot as other considerations will allow.
 - B. radiation should proceed from as large a focal spot as other considerations will allow.
 - C. the film should be as far as possible from the object being radiographed.
 - D. the distance from the anode to the material examined should be as small as is practical.

15. In order to increase the intensity of x-radiation:

- ☒ A. the tube current should be increased.
- ☐ B. the tube current should be decreased.
- ☐ C. the test specimen should be moved further from the film.
- ☐ D. a lower kilovoltage should be applied to the tube.

16. Excessive exposure of film to light prior to development of the film will most likely result in:

- ☒ A. a fogged film.
- ☐ B. poor definition.
- ☐ C. streaks.
- ☐ D. yellow stain.

17. White crescent-shaped marks on an exposed x-ray film will most likely result from:

- ☒ A. crimping film after exposure.
- ☐ B. crimping film before exposure.
- ☐ C. sudden extreme temperature change while processing.
- ☐ D. warm or exhausted fixer.

18. Reticulation resulting in a puckered or netlike film surface is probably caused by:

- ☒ A. crimping film after exposure.
- ☐ B. sudden extreme temperature change while processing.
- ☐ C. water or developer on unprocessed film.
- ☐ D. excessive object-to-film distance.

19. If an exposure time of 60 seconds was necessary using a 4-metre source-to-film distance for a particular exposure, what time would be necessary if a 2-metre source-to-film distance is used and all other variables remain the same?

- ☐ A. 120 seconds.
- ☐ B. 30 seconds.
- ☒ C. 15 seconds.
- ☐ D. 240 seconds.

20. A penetrameter on the film side of the object is used to indicate:

- ☐ A. the size of discontinuities in a part.
- ☐ B. the density of the film.
- ☒ C. the amount of film contrast.
- ☐ D. the quality of the radiographic technique.

21. A fluorescent intensifying screen will:

- ☒ A. transform ^{electromagnetic} x-ray energy into visible or ultraviolet light to which a photographic emulsion is sensitive.
- ☐ B. result in reticulation.
- ☐ C. decrease the graininess of the image when using gamma rays.
- ☐ D. increase the definition in a radiograph.

22. Lead foil screens are used in radiography:

- ☐ A. to improve the quality of the radiograph by preferentially reducing the effect scatter.
- ☐ B. to reduce the exposure time.
- ☒ C. both A and B are reasons for using lead foil screens.
- ☐ D. neither A nor B are reasons for using lead foil screens.

23. To prevent excessive backscatter from reaching a radiographic film, one should:
- ☒ A. back the cassette with a sheet of lead, the thickness needed depending on the radiation quality.
 - B. place a mask between the specimen and the front surface of the film.
 - C. back the exposure holder with a thick sheet of lead (at least 0.5 inch).
 - D. place a filter in the x-ray or gamma ray beam near the source or x-ray tube.
24. The purpose of agitating an x-ray film during development is to:
- ☒ A. protect the film from excessive pressure.
 - ☒ B. renew the developer at the surface of the film.
 - C. disperse unexposed silver grains on the film surface.
 - D. prevent reticulation.
25. When manually processing films, the purpose for sharply tapping hangers two or three times after the films have been lowered into the developer is to:
- A. disperse unexposed silver grains on the film surface.
 - ☒ B. prevent frilling.
 - ☒ C. dislodge any air bubbles clinging to emulsion.
 - ☒ D. all of the above.
26. The activity of the developer solution is maintained stable by:
- A. constant agitation.
 - B. maintaining processing solutions within the recommended temperature range.
 - ☒ C. avoiding contamination from the water wash.
 - ☒ D. addition of replenisher.
27. The purpose of fixation is:
- A. to remove all the undeveloped silver salts of the emulsion.
 - B. to leave the developed silver as a permanent image.
 - ☒ C. to harden the gelatine.
 - ☒ D. all of the above.
- 6 mins fix time.*
28. Water spots on films can be minimized by:
- ☒ A. rapid drying of wet film.
 - ☒ B. immersing wet film for one or two *seconds* minutes in a wetting agent solution.
 - C. by using a fresh fixer solution.
 - D. by cascading water during the rinse cycle.
29. The small area in the x-ray tube from which the x-radiation emanates is called the:
- ☒ A. focal spot.
 - B. filament.
 - C. focusing cup.
 - D. cathode.
- 1-4 mm focal spot size*

30. With a given exposure time and kilovoltage, a properly exposed radiograph is obtained with a 6 milliamperage-minutes exposure at the distance of 20 inches. It is desired to increase the sharpness of detail in the image by increasing the source-to-film distance to 40 inches. The correct milliamperage-minutes exposure to obtain the desired radiographic density at the increased distance is:

A. 12 milliamperage-minutes.
B. 24 milliamperage-minutes.
C. 3 milliamperage-minutes.
D. 1.7 milliamperage-minutes.

31. A graph showing the relation between material thickness, kilovoltage and exposure is called:

Same. { A. a bar chart.
B. an exposure chart or technique chart.
C. a characteristic curve.
D. a H & D curve.

32. A graph which expresses the relationship between the logarithm of the exposure applied to a photographic material and the resulting photographic density is called:

A. a bar chart.
B. an exposure chart.
C. the characteristic curve.
D. a logarithmic chart.

33. Two X-ray machines operating at the same nominal kilovoltage and milliamperage settings:

A. will produce the same intensities and qualities of radiation.
B. will produce the same intensities but may produce different qualities of radiation.
C. will produce the same qualities but may produce different intensities of radiation.
D. may give not only different intensities but also different qualities of radiation.

34. When producing radiographs, if the kilovoltage is increased:

A. the subject contrast decreases.
B. the film contrast increases.
C. the subject contrast increases.
D. the film contrast decreases.

35. An unshielded isotope source gives a dosage rate of 900 mR per hour at 10 feet. What would the unshielded dosage rate be at 30 feet?

A. 300 mR/hr.
B. 600 mR/hr.
C. 100 mR/hr.
D. 2700 mR/hr.

Now Grey.

36. Beta particles are:

A. neutrons.
B. protons.
C. electrons.
D. positrons.

37. The lead symbol "B" is attached to the back of the film cassette to determine:

- ☒ A. sensitivity.
- ☐ B. whether excessive backscatter is present.
- ☐ C. radiographic contrast.
- ☐ D. density.

38. During manual film processing, the purpose of the stop bath is to:

- ☒ A. change the exposed silver salts to black metallic silver.
- ☐ B. neutralize the developer and stop the developing process.
- ☐ C. eliminate most water spots and streaks.
- ☐ D. none of the above.

39. A large source size can be compensated for by:

- ☒ A. increasing the source-to-specimen distance.
- ☐ B. addition of lead screens.
- ☐ C. increasing the specimen-to-film distance.
- ☐ D. increasing penumbra.

40. X-rays and gamma rays are:

- ☒ A. particulate radiations.
- ☐ B. electromagnetic radiations.
- ☐ C. microwave radiations.
- ☐ D. all the above.

Film Factors

Medium = 25-80 film factor,

BS 3971-IQI

BS 2910-Pipes

BS 2600 Fused Plates

Part 1 2-50 mm

" 2 50-200 mm

ULTRASONIC TESTING

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1 ULTRASONIC TESTING—OVERVIEW

The ultrasonic testing method uses the ability of high frequency sound waves, typically above 1 MHz (1,000,000 c.p.s.), to pass through materials.

A *probe* containing one or two piezo electric crystals is used to transmit and receive ultrasonic pulses. Ultrasound hitting any air interface, or an interface with a different material density, which is perpendicular to the ultrasonic beam is reflected back and displayed on a cathode ray tube (c.r.t.). The actual display relates to the time taken for the ultrasonic pulses to travel the distance to an interface and back, i.e. longer the time taken, the further away the interface.

An interface could be the opposite side of the plate, therefore wall thickness measurements can easily be made; the interface could be a defect, therefore defect detection and sizing is possible.

Lamination checks are easily carried out using ultrasonic methods; the opposite is true for radiography. Welds can be tested using *angle* type probes, although this requires more operator skill to apply and interpret results. Defects in welds can usually be located but the type of defect may be difficult to identify.

To detect a linear defect with radiography, the defects main axis must be in line with the radiation beam; the opposite is true for ultrasonic flaw detection, i.e. when using ultrasonic testing the defects should ideally have their major face at 90° to the axis of the ultrasonic beam.

To enable the ultrasound to enter the test material, a couplant must be introduced, e.g. grease, oil, glycerine or water, between the probe and the test surface. If couplant was omitted ultrasonic testing would not be possible, because ultrasound does not travel very well through air.

One major disadvantage with commonly used portable equipment is that no permanent record is produced, some manufacturers are now trying to rectify this situation although the equipment available is currently expensive.

2 ULTRASOUND

2.1 Definition of ultrasound

Sound consists of periodic mechanical vibrations and waves which can travel through solids, liquids or gases.¹ There are various ways or *modes* in which the sound may travel, but all involve the movement of particles which make up the medium through which the sound is travelling. Sound will therefore not travel through a vacuum.

The human ear can detect sound up to a frequency of approximately 20,000 cycles per second (c.p.s.), the sound beyond this audible frequency is termed *ultrasound*.

For N.D.T. purposes the test frequency² range used on metals is from 500,000 c.p.s. (0.5 MHz) to 25,000,000 c.p.s. (25 MHz).

2.2 The production of ultrasound

2.2.1 Piezo-electric crystals

Ultrasound for N.D.T. purposes is normally produced by crystals which use the *piezo electric effect*. This effect is the property which certain crystals have of producing electrical energy when subjected to mechanical force, and conversely, the crystals distort and produce mechanical energy when they receive an electric current.

1 Not all wave types will be supported by liquids and gases.

2 *Frequency*, in this context, is the number of cycles which would pass a fixed point per second. Do not confuse with *pulse repetition frequency (p.r.f.)* which is the number of electrical pulses supplied to the probe crystal per second.

Piezo electric crystals are sometimes referred to as *transducers*. A transducer is something which can convert one form of energy into another.

If a piezo electric crystal is subjected to pulses of electric energy it will vibrate at a frequency determined by the applied current and the crystal thickness. Thin crystals produce high frequency waves, thick crystals produce low frequency waves.

The frequency of the ultrasound produced is proportional to the frequency of crystal vibrations.

The same crystal used to transmit ultrasonic energy may also be used to receive ultrasonic energy, i.e. convert sound waves received into an electric current.

Crystal types suitable for use in ultrasonic testing are as follows:

- a. Quartz: naturally occurring; hard and stable.
- b. Barium titanate: ceramic; excellent transmitter of ultrasound; good overall efficiency; heat over 140°C destroys its properties.
- c. Lead zirconate titanate: ceramic; good overall efficiency and sensitivity; commonly used for industrial ultrasonic testing.
- d. Lead metaniobate: capable of transmitting very narrow pulses; not as sensitive as barium titanate; commonly used for industrial ultrasonic testing.
- e. Lithium sulphate: excellent receiver of ultrasound; used little in industrial N.D.T.—dissolves in water.

2.2.2 Probes

An ultrasonic probe is an assembly which fixes the crystal(s) at the required angle and allows for the attachment of electrical connections to relay electrical signals from the main test unit to the probe, and from the probe back to the test unit.

Probes also contain a damping medium, typically an epoxy or phenolic resin, which prevents the crystal(s) from vibrating too long (ringing) after they have received an electrical pulse. This results in better signal resolution on the c.r.t., i.e. separate signals are more easily identified.

Probes are categorized as to whether they consist of a single crystal, two crystals (twin crystals) or many crystals; the latter type is rarely encountered.

In a single crystal probe, the crystal acts as a transmitter and a receiver, similar to a two-way radio, i.e. the crystal will only receive when the talk is off. In a twin crystal probe, one crystal transmits and the other receives.

Probes are also categorized by the angle at which they transmit ultrasound into the test material. Two main divisions exist:

- 0° or normal probes;
- angle probes, e.g. 45°, 60°, 70°.

Probes are further categorized by the type of wave, or main type of wave, they transmit into the test specimen:

- compression or longitudinal waves;
- shear or transverse waves;
- surface or Rayleigh waves;
- plate or Lamb waves.

2.3 Wave types

2.3.1 Compression or longitudinal waves

These waves travel through a medium causing the particles of the material to oscillate parallel with the axis of the beam.

Compression waves are produced in steel if the *incident angle* of the beam in perspex is less than approximately 27.4° .

Probes which produce compression waves will normally have an incident angle of 0° , or close to 0° , thereby producing no refraction of the beam transmitted into the test material.

Longitudinal waves can travel in solids, liquids and gases.

2.3.2 Shear or transverse waves

These waves travel through a medium causing the particles of the material to oscillate at 90° to the direction of travel.

Shear waves only¹ are produced in steel if the *incident angle* of the beam in perspex is between approximately 27.4° and 56.4° .

In practice, we are more concerned with *refracted angles*, i.e. we wish to know the angle of the ultrasound travelling through the material under test, rather than the angle of the ultrasound travelling through the perspex shoe.

Common refracted angles or *probe angles* used for steel are 45° , 60° and 70° .

Transverse waves will travel in solids only, i.e. they will not be supported in liquids or gases.

2.3.3 Surface or Rayleigh waves

Surface waves are not often used in industrial N.D.T. although they do have some applications in the aerospace industry. Their mode of propagation is elliptical along the surface of a material up to a depth of one wavelength. They travel at a velocity of 90% of that for a corresponding shear wave.

2.3.4 Plate or Lamb waves

These waves may exist in many modes and are used to detect flaws in plate material. Some modes will detect only surface flaws similar to surface waves while others may also detect sub-surface flaws. Plate waves may be thought of as a complex combination of compression and shear waves.

3 THE ULTRASONIC TEST UNIT

3.1 General

There is a variety of ultrasonic test equipment available from a variety of manufacturers, however, portable test equipment using an *A-scan* display on a c.r.t. is by far the most commonly used.

¹ It is possible to produce more than one type of wave in a material at the same time, e.g. compression and shear waves; this is undesirable for testing purposes.

3.2 Displays

Ultrasonic data may be displayed on a c.r.t.¹ in a variety of ways:

A-scan: Displays received pulse amplitude (usually on y-axis) against pulse travel time (usually on x-axis).

B-scan: Shows a two-dimensional graphical plot of the cross-sectional plane scanned which is normal to the test surface, e.g. may display the apparent size and position of a defect in the *end* or *macro* view of a weld.

C-scan: Shows a two-dimensional graphical projection of a scanned area in plan view to the test surface, e.g. may display the apparent size and position of a defect in the *plan* view of a weld.

D-scan: Shows a two-dimensional graphical projection of a scanned area normal to the test surface and normal to the projection of the beam, e.g. may display the apparent size and position of a defect in the *side* view of a weld.

3.3 A-scan display on a c.r.t.

The main component of an ultrasonic set for A-scan display is the c.r.t. which displays the results of any checks performed. The c.r.t. consists of a phosphor screen which emits light when struck by electrons which are constantly fired at the screen. The area of the screen struck by the electrons is governed by the X and Y plates, which deflect the electron beam.

The X plates are connected to a sweep generator which is set to ensure the electron beam is constantly sweeping the screen from left to right, producing a displayed bright line known as the *time base*.

The Y plates govern the vertical movement of the electron beam, these are connected, via a receiver amplifier and attenuation/gain control, to any incoming signals from the probe. Any incoming signals cause the time base to deflect upwards at a point along its length which is dependant on the distance of the reflector from the crystal(s) in the probe.

3.4 Pulse generator (timer)

The pulse generator triggers the electrical pulses which are sent to the transmitter circuit and the time base circuit. The pulse repetition frequency (p.r.f.) is typically between 50 and 4800 pulses a second.

3.5 Pulse transmitter

The pulse transmitter delivers electrical energy to the crystal.

3.6 Time base circuit (sweep generator)

This circuit provides the green line of the time base by *sweeping* the electron beam horizontally across the screen.

3.7 Receiver amplifier

The receiver amplifier accepts and amplifies returning electrical pulses. An amplification of 10,000 to 100,000 times is necessary because of the low energy of the returning electrical signals. The amplifier must also reproduce the signals on the c.r.t. in direct proportion to the incoming signals, i.e. input/output should be linear.

¹ There are other methods of displaying ultrasonic data, e.g. on liquid crystal displays and facsimile.

3.8 Controls

3.8.1 Range or calibration control

This control governs the distance represented by the full screen width and has the effect of closing up or separating any signals on the screen when adjusted. For example, adjusting the range may allow for a calibration across the full screen width to be 0-50 mm (50 mm range); 0-100 mm (100 mm range); 50 mm-150 mm (100 mm range); 37-253 mm! (216 mm range) etc.. The range control may allow the display to represent any distances from approximately 10 mm to 10 m. There are usually separate controls for *coarse* and *fine* range adjustment.

3.8.2 Delay control

The delay control has the effect of moving any signals visible on the screen to the left or right without altering the distance between them, e.g. for a fixed 50 mm range, altering the delay may allow for a calibration across the full screen width to be 0-50 mm, 50-100 mm, or 100-150 mm.

3.8.3 Gain/attenuation control

The gain control adjusts the amplification of incoming signals, and therefore the amplitude of any signals displayed on the c.r.t. display. On most ultrasonic sets this control operates in steps and is calibrated in decibels (dB). There are usually two separate controls for adjustment of gain, e.g. 20 dB and 2 dB.

3.8.4 Miscellaneous controls

The range, delay and gain controls are the main controls which an operative will use every time the test equipment is used. Other controls/switches present may include:

- a. Double/single crystal selection switch: Sometimes this control is incorporated with the *on/off* switch.
- b. Focus control: Adjusts the displayed trace so that it is as sharp as possible.
- c. Reject or suppression control: *Rejects* or *suppresses* any signal below a certain amplitude and can be used to remove small unwanted signals from the trace. This control has the effect of making the amplifier non-linear and therefore defect sizing using the 20 dB or 6 dB drop technique should not be carried out with the reject control set above a certain level.

4 THE DECIBEL (dB)

The decibel is a logarithmic unit used to compare sound intensities.

The actual sound energy being transmitted by a probe is not known, therefore we can only compare sound intensities and express them as a ratio, i.e. twice as much, ten times as much etc..

A change in sound intensity, expressed in dB, can be measured by comparing signal heights on a calibrated c.r.t.. The change in dB is given by the formula:

$$dB = 20 \log_{10} \frac{L_1}{L_2}$$

Where: L_1 and L_2 are the signals being compared.

Example 1:

For two signals, one twice as high as the other, the difference in dB would be:

- a. $dB = 20 \log_{10} \frac{L_1}{L_2}$
- b. $dB = 20 \log_{10} \frac{2}{1}$
- c. $dB = 20 \log_{10} 2$
- d. $dB = 20 \times 0.3010$
- e. $dB = 6.020$

Example 2:

For signals differing in height by a factor of ten, the difference in dB would be:

- a. $dB = 20 \log_{10} \frac{L_1}{L_2}$
- b. $dB = 20 \log_{10} \frac{10}{1}$
- c. $dB = 20 \log_{10} 10$
- d. $dB = 20 \times 1.000$
- e. $dB = 20$

Example 3:

Two reflectors, equidistant from the probe, have a dB difference of 14 dB between their echo heights. What is the ratio of their respective echo heights?

- a. $dB = 20 \log_{10} \frac{L_1}{L_2}$
- b. $14 = 20 \log_{10} \frac{L_1}{L_2}$
- c. $\frac{14}{20} = \log_{10} \frac{L_1}{L_2}$
- d. $\text{Antilog } 0.7 = \frac{L_1}{L_2}$
- e. $5 = \frac{L_1}{L_2} \therefore \text{ratio} = 5:1$

The gain/attenuation controls on a conventional ultrasonic flaw detection unit are calibrated in decibels, e.g. if we reduce the intensity of ultrasound by 6 dB, any signal on the c.r.t. will drop to a half of its initial height.

It is important to note that if *suppression* is introduced to remove small unwanted signals, the linearity of the larger signal heights will be adversely affected.

Note: To increase the sound intensity by two times, or to reduce the intensity by half, we must increase or decrease by 6 dB respectively. To increase the sound intensity by ten times, or to reduce the intensity to a tenth, we must increase or decrease by 20 dB respectively.

5 VELOCITY, FREQUENCY AND WAVELENGTH RELATIONSHIP

The velocity of ultrasound depends on the type of wave transmitted, for example, compression waves typically travel twice as fast as transverse waves in the same material. This is because the different types of ultrasonic wave differ in their *mode of propagation*.

Ultrasound velocity also depends on the density and elasticity of the medium the waves are passing through.

Formula for longitudinal velocity:

$$C_l = \sqrt{\frac{E}{\rho} \times \frac{1 - \sigma}{(1 + \sigma) \times (1 - 2\sigma)}}$$

Where: C_l = m/s
 E = Young's modulus (N/m²)
 ρ = density (kg/m³)
 σ = Poisson's ratio

Formula for transverse velocity:

$$C_t = \sqrt{\frac{E}{\rho} \times \frac{1}{2(1 + \sigma)}}$$

Where: C_t = m/s
 E = Young's modulus (N/m²)
 ρ = density (kg/m³)
 σ = Poisson's ratio

Velocities for compression waves and shear waves		
Material	V_c m/s	V_s m/s
Air	332	—
Aluminium	6350	3080
Brass (70-30)	4372	2100
Cast iron	4500-4800	2160-2580
Copper	4769	2325
Gold	3240	1200
Iron	5957	3224
Lead	2400	790
Oil	1440	—
Perspex	2740	1320
Carbon steel	5960	3240
Stainless steel	5740-6100	3130-3360
Water	1483	—
Tungsten	5174	2880
Zinc	4170	2480
Zirconium	4650	2300

Like audible sound, ultrasound is produced in wave form. If we know the frequency and velocity of ultrasound travelling through a medium, we can calculate the ultrasound's wavelength:

$$\lambda = \frac{c}{f}$$

Where: λ = wavelength (m)
 c = velocity (m/s)
 f = frequency (c.p.s.)

More conventionally the wavelength is expressed in millimetres, therefore the following formula applies:

$$\lambda = \frac{c \times 1000}{f}$$

Where: λ = wavelength (mm)
 c = velocity (m/s)
 f = frequency (c.p.s.)

Example:

What is the wavelength of ultrasound if a 5 MHz compression wave probe is used on steel?

a. $\lambda = \frac{c \times 1000}{f}$

b. $\lambda = \frac{5960 \times 1000 \text{ m/s}}{5,000,000 \text{ c.p.s.}}$

c. $\lambda = 1.192 \text{ mm}$

6 ULTRASONIC TECHNIQUES

6.1 General

Ultrasonic testing may be carried out by using the *transmission technique* or the *pulse-echo technique*. See also *time of flight diffraction technique* in Appendix B.

Both the transmission and pulse-echo techniques may use the probe(s) in contact with the specimen—known as a *contact technique*; or the ultrasound may pass via a water path before entering the specimen—known as an *immersion technique*.

6.2 Transmission technique

The transmission technique requires two probes; one for transmitting and one for receiving.

The *through transmission technique* requires access to both sides of the object under test. Any flaw located in the beam path will reduce or eliminate the received signal, indicating the flaws presence. No flaw depth or flaw profile information is given.

Any loss of contact with a test specimen, or a loss of couplant, will also cause the received signal to reduce in amplitude or disappear completely—this can give rise to incorrect interpretations of the test results.

The transmission technique can be used with angle probes and therefore eliminate the need for access to both sides; this may be referred to as the *pitch and catch technique*.

6.3 Pulse-echo technique

This technique uses only one probe. Because the ultrasound is transmitted and received by a single probe (single crystal or twin crystal), assessment of distance, e.g. to a flaw or backwall, is easily carried out. The characteristics of the received signal can also give an indication of the nature of the flaw.

7 PROPAGATION OF ULTRASOUND

7.1 General

The propagation of ultrasonic waves in a material is dependant on the density and elastic properties of that material and the type of wave transmitted.

The practical considerations which will affect propagation will include:

- a. the test material's grain size,
- b. attenuation (absorption and scatter effects),
- c. acoustic impedance of the test material,
- d. characteristic impedances of inclusions,
- e. diffraction,
- f. lack of homogeneity,
- g. anisotropic materials¹.

7.2 Acoustic impedance

Acoustic impedance is the resistance of a material to the passage of ultrasound.

It is the acoustic impedance difference between two different materials/mediums which governs the intensity of ultrasound reflected from the interface between them. Conversely, the amount of ultrasound passing from one material to another depends on this difference between the two materials; this difference is termed the *acoustic impedance ratio*.

If the acoustic impedances of two materials in intimate contact were identical, no reflection of ultrasonic waves would occur at the interface between them, i.e. 100% ultrasound transmission would occur.

Air has a very high acoustic impedance compared to steel and therefore will produce very little transmission of ultrasound across the interface between them, in fact the reflection would be close to 100%.

The acoustic impedance of a specific medium can be calculated by using:

$$Z = \rho c$$

Where: Z = acoustic impedance: $(\text{g/cm}^2\text{-sec}) \times 10^6$
 ρ = density of material: g/cm^3
 c = velocity of ultrasound in the material: $\text{cm} \times 10^6/\text{s}$

The acoustic impedance ratio between two mediums can be found by using:

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2 \times 100$$

Where: R = reflected energy %
 Z_1 = acoustic impedance of first medium
 Z_2 = acoustic impedance of second medium

¹ The grains are random in orientation and have different elastic properties in different directions.

Example:

What percentage of ultrasound energy is reflected from a steel/water interface? (Steel: $Z = 45$; water: $Z = 1.5$)

- a. $R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2 \times 100$
- b. $R = \left(\frac{45 - 1.5}{45 + 1.5} \right)^2 \times 100$
- c. $R = \left(\frac{43.5}{46.5} \right)^2 \times 100$
- d. $R = 87.5\%$

The example given above shows that 87.5% of the ultrasonic energy is reflected when the ultrasound reaches the interface between steel and water, therefore ~~only 12.5%~~ is being transmitted into the second medium.

7.3 Couplant

Ultrasound in shear mode will not travel through air or any other gases. Ultrasound in compression mode will travel through air, but because of a huge acoustic impedance difference between a solid and a gas, the transmission of ultrasound into a test item from the air is not possible in practical terms.

Therefore it is necessary to introduce a medium, usually liquid or paste, between the probe and the specimen to enable the ultrasound to be transmitted from one to the other.

Common couplants used:

- a. Glycerine.
- b. Swarfega.
- c. Polycell-wallpaper paste.
- d. Grease.
- e. Water.

It is not advisable to use water based couplants on test blocks due to corrosion. For many product test applications, water based couplants are specified/required due to the difficulty in removing grease based couplants from the surface prior to coating/painting.

7.4 Attenuation

When sound travels through a material, it loses energy as it proceeds, this energy loss is known as *attenuation*.

Attenuation is the process by which the *intensity* of the ultrasonic waves are reduced or *attenuated* by the physical structure of the material. The reason for this attenuation is due to the *absorption* and *scattering* of the ultrasonic waves. Attenuation is usually measured in decibels per millimeter (dB/mm).

Absorption of the ultrasonic waves relates to the heat losses caused by internal friction; absorption is greater with higher frequencies.

Scattering, which is multi-directional, occurs when the frequency of the probe chosen for use has a wavelength which approaches the grain size of the material under test.

The attenuation of the acoustic intensity of the beam is caused by fine inclusions, porosity, the material's grain structure and composition.

See also Appendix A.

7.5 Diffraction

Diffraction may be defined as a wave passing near an object and having a tendency to become bent towards it and around it. Diffraction may occur during standard pulse echo flaw detection when a flaw exists with small dimensions in relation to the ultrasound wavelength; i.e. no specular reflection may occur and therefore no echo will exist on the display.

8 REFLECTION—REFRACTION—SNELLS LAW

8.1 Reflection

Ultrasonic waves are reflected by objects or interfaces in their path. The angle at which this reflection takes place is governed by the law of reflection, which states:

Angle of incidence = angle of reflection.

8.2 Refraction

Refraction is the term used to explain what happens to an ultrasonic beam when it passes from one medium (at velocity 1) to a different medium (at velocity 2), e.g. from perspex to steel or vice versa.

The relationship between the incident and refracted angles is governed by *Snells Law* which states:

$$\frac{\sin \alpha}{\sin \beta} = \frac{V_1}{V_2}$$

Where: α = angle of incidence
 β = angle of refraction
 V_1 = velocity of ultrasound in first medium
 V_2 = velocity of ultrasound in second medium

Example:

What is the refracted (probe) angle in steel if the incident angle in the probe is set at 40°?

a. $\frac{\sin \alpha}{\sin \beta} = \frac{V_1}{V_2}$

b. $\sin \beta = \frac{V_2}{V_1} \times \sin \alpha$

c. $\sin \beta = \frac{3240 \text{ m/s}}{2740 \text{ m/s}} \times \sin 40^\circ$

d. $\sin \beta = 1.182 \times 0.642$

e. $\sin \beta = 0.7598$

f. $\beta = 49^\circ 27'$

8.3 Mode conversions

A mode conversion can take place when an ultrasonic beam is incident upon a surface at an angle other than 90°. It is simply the conversion of one mode of propagation to another, e.g. compression waves to shear waves, or vice versa.

A mode conversion is achieved when a compression wave passes from the perspex shoe of a conventional angle beam probe, or more correctly from the couplant, into a steel test item. Remember that liquid couplant will only support compression waves. A mode conversion is also achieved on any returning waves.

When mode conversions occur within the material being examined they can lead to spurious indications on the display.

9 THE ULTRASONIC BEAM

9.1 The dead zone

Flaws, or other reflectors, lying in the dead zone region of the beam will not be detected. The dead zone can be seen at the start of a trace on a c.r.t. displaying A-scan, but only with single crystal probes.

The dead zone increases when the probe frequency decreases.

9.2 The near zone

In this region of the beam, the sound intensity does not vary uniformly owing to wave interference.

Reflectors/flaws lying in this zone may appear smaller or larger than their actual size; the signal heights displayed on the c.r.t. are unpredictable so it is desirable to keep the near zone length to a minimum.

The near zone length can be calculated using the following formula:

$$\text{Near zone length (mm)} = \frac{D^2}{4\lambda}$$

Where: D = crystal diameter (mm)
 λ = wavelength (mm)

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Since $\lambda = \frac{c}{f}$, the near zone formula may also be written:

$$\text{Near zone length (mm)} = \frac{D^2 \times f}{4 \times c}$$

Where: D = crystal diameter (mm)
 f = frequency (c.p.s.)
 c = velocity (mm/s)

It can be seen from the formula that the near zone can be decreased by decreasing the crystal diameter or decreasing the probe frequency.

Example:

Calculate the near zone length in steel for a 5 MHz compression wave probe 10 mm diameter.

- a. $\text{Near zone length (mm)} = \frac{D^2 \times f}{4 \times c}$
- b. $\text{Near zone length (mm)} = \frac{10^2 \times 5,000,000}{4 \times 5960,000}$
- c. $\text{Near zone length (mm)} = \frac{50,000}{2384}$
- d. $\text{Near zone length (mm)} = 20.97 \text{ mm}$

9.3 The far zone

In the far zone of the ultrasonic beam there is no wave interference therefore the sound intensity in this zone is predictable.

The sound intensity reduces from 100% in the centre to 0% at the edge of the beam, therefore when the centre of the beam hits a reflector/ flaw the amplitude of the signal on the c.r.t. will be at its maximum.

The sound intensity will also decrease with a greater distance (in the range axis) to a reflector/ flaw.

The amount of beam divergence depends upon the crystal size and the wavelength as shown in the following *half angle beam spread formula*:

$$\sin \theta = \frac{K\lambda}{D}$$

Where: θ = the half angle
 K = a constant
 λ = wavelength (mm)
 D = crystal diameter (mm)

Since $\lambda = \frac{c}{f}$, the formula may also be written:

$$\sin \theta = \frac{K \times c}{D \times f}$$

Where: D = crystal diameter (mm)
 f = frequency (c.p.s.)
 c = velocity (mm/s)

It may be seen from the above formula, that the beam divergence can be decreased by increasing the crystal diameter or increasing the probe frequency. Unfortunately this will extend the length of the near zone. So in probe design there is a compromise to obtain minimal beam spread and near zone.

Example:

Calculate the 0% half angle in steel for a 4 MHz compression wave probe with a 10 mm crystal diameter.

a. $\sin \theta = \frac{K \times c}{D \times f}$

b. $\sin \theta = \frac{1.22 \times 5,960,000}{10 \times 4,000,000}$

c. $\sin \theta = \frac{727.12}{4000}$

d. $\sin \theta = 0.1818$

e. $\theta = 10.47^\circ (10^\circ 28')$

9.4 Side lobes

Side lobes are secondary lobes to the primary ultrasonic beam or *main lobe* which are formed at the face of a transducer and radiate away from the main lobe. They represent areas of high and low acoustic intensities and may cause unwanted echoes to be received by the probe, especially on rough surfaces, which may be mistaken for flaws on the c.r.t..

For shear wave probes, the minimum beam angle in steel is approximately 33° to 35°, but at these relatively acute angles, side lobes may be formed which, although usually negligible, may cause spurious indications on the c.r.t.. For this reason it is usually safer to set the minimum beam angle for shear wave probes in steel at 40°.

The narrower the main lobe, i.e. the smaller the half-angle of the beam, the weaker and more numerous the side lobes.

10 RESOLUTION

Resolution or *resolving power*, or more correctly *range resolution*, relates to the ability of an ultrasonic flaw detection system to differentiate between two or more discontinuities which lie in close proximity in the range axis.

Range resolution is governed by the pulse length produced by a probe. The smaller the pulse length the better the resolution.

The shape of an ultrasonic pulse is governed by the following variables:

- a. Frequency (governed by crystal thickness).
- b. Amount of crystal damping.
- c. Initial energy applied to the crystal.
- d. Velocity of sound in the material.

Ideally, a pulse should build up and decay rapidly, in practice this is not possible to achieve without introducing a damping material which is in contact with the crystal to prevent any unwanted *ringing*. A crystal which has not been damped would result in a long pulse with exponential decay on intensity.

Pulse length may be determined from the following formula:

$$\lambda = \frac{c}{f} \times \text{number of waves}$$

A probe will not resolve two flaws, unless their separation is equal to or more than half the pulse length.

APPENDIX A CALCULATING ATTENUATION AND TRANSFER LOSS

A.1 Calculating attenuation

What is the attenuation in a material using a 5 MHz, 10 mm longitudinal wave probe for a plate thickness of 40 mm?

1. Calculate the near zone for a 10 mm, 5 MHz probe—answer is 21 mm.
2. If the probe is placed on the 40 mm thick section of the plate, we will obtain signals on a 0-200 mm calibrated time base at 40 mm, 80 mm, 120 mm, 160 mm, 200 mm.
3. Three near zones¹ need to be taken into consideration therefore $3 \times 21 = 63$ mm. The first signal beyond 63 mm is the repeat reflection at 80 mm. The second signal (80 mm) and the fourth signal (160 mm) will be used for comparison.
4. If the signal amplification difference between the second and fourth signals was 11 dB and the total path distance travelled between the second and fourth signal was 160 mm ($2 \times$ beam path for 80 mm), then the attenuation at 5 MHz would be:

$$\frac{11 - 6}{160} \text{ dB per mm} = .03125 \text{ dB/mm} (.03 \text{ dB/mm})$$

6 dB was deducted from 11 dB because -6 dB was due to the law of large reflectors and represented a half of the reference signal.

The remaining 5 dB was due to attenuation over the given path length.

A.2 Measurement of transfer loss and attenuation

1. With the flaw detector calibrated for shear wave pulse echo, place two identical shear wave probes in opposition to each other on the surface of the *calibration block*, one full skip distance apart.
2. Having obtained the maximum echo, mark the tip height with chinagraph on the screen of the c.r.t.
3. Keeping the same gain setting, repeat this exercise at two skip distances apart, then three skips, etc.. until a decay curve for the calibration block can be drawn by joining these points.
4. Repeat this exercise at one skip distance apart on the *specimen* under test, keeping the same gain setting. Note how many decibels of gain are required to raise the maximum echo obtained on the specimen to the decay curve for the calibration block; this is the transfer loss and attenuation difference between the calibration block and the specimen.

¹ The radiation laws for large reflectors states that the amplitude of a signal will half if the distance is doubled. This statement is true when the distance being considered is beyond three near zones, with the reference signal set at a given height.

APPENDIX B THE TIME OF FLIGHT DIFFRACTION TECHNIQUE (TOFD)

This technique can be used to locate flaws using a wide ultrasonic beam to achieve full volumetric coverage of a weld in a single pass, but is normally used to size cracks or vertical planar flaws by measuring the flaw tip depths. TOFD data is usually displayed using *B-scan* or *D-scan* presentations.

Compression waves from wide beam spread probes, or angled compression wave probes, incorporating steel or aluminium shoes, are used to transmit the ultrasonic energy. The weak diffracted waves from flaw tips are detected using similar receiver probes on the opposite side of the weld.

The TOFD method only sizes the through thickness depth of flaws, the accuracy often being within ± 0.5 mm. Flaw orientation angles up to 30° (from the normal to the surface) can also be determined, by measuring the transmitter stand-off distance from an appropriate surface reference point and noting the diffraction positions from the top and bottom of the flaw.

If a surface breaking crack exists, no lateral echo or surface diffraction echo is obtained, only the diffraction echo from the crack tip is received.

The TOFD system is not greatly influenced by changes in crack tip transparency due to compression stresses or if the discontinuity contains liquid or solid matter; this gives the technique an advantage over the other methods.

It is possible for 75° to 80° shear wave probes to be used, but this often results in difficulty in the location of diffraction echoes in the presence of mode change echoes which may occur earlier in time than the backwall echo.

APPENDIX C ECHODYNAMIC PATTERNS

An echodynamic pattern is defined in BS 3923 : Part 1 as: 'the form of change in signal height and shape on traversing the ultrasonic beam in two mutually perpendicular directions across an imperfection'. The following echodynamic patterns are identified:

Pattern 1:

The A-scan presentation shows a single sharp echo which rises smoothly in amplitude to a single maximum before falling smoothly to zero. The following diagram shows Pattern 1 from a point reflector.

Pattern 2:

The A-scan presentation shows a single sharp echo for all probe positions. As the probe is scanned the amplitude rises smoothly to a plateau, which is held with or without minor (± 4 dB) amplitude variations with further probe movement, before falling smoothly to zero. The following diagram shows Pattern 2 from a large smooth planar reflector near normal incidence.

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Pattern 3a:

The A-scan presentation shows a single ragged echo for all probe positions. As the probe is scanned, the echo shows large (+6 dB) random fluctuations in amplitude. The following diagram shows Pattern 3a from a large irregular reflector near normal incidence.

Pattern 3b:

The A-scan presentation shows an extended train of signals (subsidiary peaks) within a bell-shaped pulse envelope. As the probe is scanned, each subsidiary peak travels through the pulse envelope, rising to its own maximum amplitude towards the centre, and then falling.

The overall signal shows large (+6 dB) random fluctuations in amplitude. The following diagram shows Pattern 3b from a large irregular reflector at oblique incidence.

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Pattern 4:

The A-scan presentation shows a cluster of signals which may be resolved or unresolved in range. The following diagram shows Pattern 4 from a multiple imperfection. As the probe is scanned, the signals rise and fall at random, each separate signal, if resolved, showing Pattern 1 response.

APPENDIX D BS 3923—TEST PROCEDURE AND REPORTING

D 1 Test procedure

The BS 3923—*Methods for ultrasonic examination of welds* requires a test procedure to be prepared for the particular weld or class of welds to be examined.

The following information and instructions must either be included in the test procedure or be given to the operator through other relevant documentation:

- a. examination Level,
- b. type(s) of ferritic parent material and form (i.e. cast, forged or rolled, etc.),
- c. manufacturing stage at which examination is to be made, and post-weld heat treatment if any,
- d. joint preparation and dimensions,
- e. welding procedure,
- f. surface condition category,
- g. couplant,
- h. type of ultrasonic flaw detector,
- i. details of scans and probes to be employed,
- j. method of sensitivity setting, and scanning and evaluation levels to be applied,
- k. design and use of special test blocks (if any),
- l. method to be used for referencing positions of imperfections (if found),
- m. reporting requirements,
- n. acceptance standard,
- o. operator qualification.

Additional Information

Immediately prior to examination, the operator must be informed of any local deviations from joint preparation drawn in the welding procedure, and shall be given details of any repairs already made.

D 2 Presentation of results

For each weld examined, the operator must submit a signed report containing the following information:

- a. job identification and material,
- b. identification of detailed test procedure,
- c. stage of manufacture at which examination was made, including state of heat treatment,
- d. identity of operator and certification status,
- e. date of test,
- f. sketch of weld configuration as inspected showing all relevant dimensions, and one or more cross-sectional views,
- g. type of ultrasonic flaw detector used (including serial number),
- h. details of probes used, including make, type and frequency,
- i. calibration block used,
- j. test sensitivity and evaluation/recording levels applied,
- k. method of correction employed for attenuation and transfer loss,

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- k. method of correction employed for attenuation and transfer loss,
- l. sketch showing extent of scanning, in particular, detailing areas which, due to the geometry or surface condition of the component, could not be fully examined in accordance with the detailed test procedure,
- m. a report on the parent metal examination describing any local heterogeneities (e.g. laminations, surface imperfections, areas of high attenuation) which may adversely affect the weld examination at such locations; if no such heterogeneities are found, a statement to this effect shall be included in the operator's report,
- n. test results in accordance with the requirements in table 30 (see 17.4), and including imperfection location in relation to the reference datum points shown in the detailed test procedure,
Note: A suggested notational system for recording imperfection dimensions is illustrated in appendix P.
- o. for flaws which lie outside the acceptance criteria, a plotted illustration of such flaws.

The operator's report shall either include a statement regarding the acceptability or otherwise of each of the recorded imperfections in relation to the acceptance standard or shall be accompanied by such a statement by a supervisor or other responsible person.

APPENDIX E STANDARDS

- BS 2704 Specification for calibration blocks for use in ultrasonic flaw detection
- BS 3683 Glossary of terms used in non-destructive testing
 Part 4: Ultrasonic flaw detection
- BS 3889 Methods for non-destructive testing of pipes and tubes
 Part 1 Methods of automatic ultrasonic testing for the detection of imperfections in wrought steel tubes
- BS 3923 Methods for ultrasonic examination of welds
 Part 1: Methods for manual examination of fusion welds in ferritic steels
 Part 2: Automatic examination of fusion welded butt joints in ferritic steels
- BS 4124 Methods for ultrasonic detection of imperfections in steel forgings
- BS 4331 Methods for assessing the performance characteristics of ultrasonic flaw detection equipment
 Part 1: Overall performance: on-site methods
 Part 2: Electrical performance
 Part 3 Guidance on the in-service monitoring of probes (excluding immersion probes)
- BS 5996 Methods for ultrasonic testing and specifying quality grades of ferritic steel plate
- BS 6208 Method for ultrasonic testing of ferritic steel castings including quality levels
- DD 174 Guide to the calibration and setting up of the ultrasonic time of flight diffraction (TOFD) technique for the location and sizing of flaws.

LEVEL 2 - ULTRASONIC TESTING - GENERAL

PAPER No. UT2G1

NAME:

COMPANY:

DATE:

SIGNED:

RESULTS:

1. Under most circumstances, which of the following frequencies would result in the best resolving power when testing C-Mn steel?

A. 1 kilohertz.
B. 1 megahertz.
C. 2 megahertz.
☒ D. 5 megahertz.

$$\lambda = \frac{v}{f}$$

2. Which of the following materials of the same alloy is most likely to produce the greatest amount of sound attenuation over a given distance?

A. A hand forging.
☒ B. A coarse grained casting.
C. An extrusion.
D. The attenuation is equal in all materials.

3. Grass on a CRT display could be caused by:

A. a crack.
B. a large inclusion.
☒ C. a coarse grained material.
D. a gas pocket.

4. A test method employing two separate probes on opposite surfaces of the material being tested is called:

A. contact testing.
B. surface wave testing.
☒ C. through-transmission testing.
D. Lamb wave testing.

5. The number of complete waves which pass a given point in a given period of time (usually one second) is referred to as the:

A. amplitude of a wave motion.
B. pulse length of a wave motion.
☒ C. frequency of a wave motion.
D. wavelength of a wave motion.

6. When the motion of the particles of a medium is *parallel* to the direction of the propagation, the wave being transmitted is called a:
- ☒ A. longitudinal wave.
 - ☐ B. shear wave.
 - ☐ C. Rayleigh wave.
 - ☐ D. Lamb wave.
7. 25 million cycles per second can also be stated as:
- ☐ A. 25 kilohertz.
 - ☐ B. 2500 kilohertz.
 - ☒ C. 25 megahertz.
 - ☐ D. 25 microhertz.
8. In an A-scan presentation, the horizontal base line represents the:
- ☐ A. amount of reflected ultrasonic sound energy.
 - ☐ B. distance travelled by the probe.
 - ☒ C. elapsed time or distance.
 - ☐ D. None of the above.
9. In an A-scan presentation, the amplitude of vertical indications on the screen represents the:
- ☒ A. amount of ultrasonic sound energy returning to the probe.
 - ☐ B. distance travelled by the probe.
 - ☐ C. thickness of material being tested.
 - ☐ D. elapsed time since the ultrasonic pulse was generated.
10. V2 contained within Snells Law represents the:
- ☐ A. amount of sound refraction in the second medium.
 - ☒ B. velocity in the second medium.
 - ☐ C. amount of ultrasound transmitted across the interface between the two materials.
 - ☐ D. near zone length in the second medium.
11. The piezoelectric material in the probe:
- ☐ A. converts electrical energy to mechanical energy.
 - ☐ B. converts mechanical energy to electrical energy.
 - ☒ C. Both A and B.
 - ☐ D. Neither A nor B.
12. The angle of incidence is:
- ☐ A. greater than the angle of reflection.
 - ☐ B. less than the angle of reflection.
 - ☒ C. equal to the angle of reflection.
 - ☐ D. not related to the angle of reflection.
13. The gradual loss of sonic energy as the ultrasonic vibrations travel through the material is referred to as:
- ☐ A. reflection.
 - ☐ B. refraction.
 - ☐ C. reproducibility.
 - ☒ D. attenuation.

Attenuation Check carried out.

40. When testing a specimen, using a 0° probe, a decrease in a wave frequency (obtained by changing the probe) will result in:

- A. an increase in sound velocity.
- B. a decrease in sound velocity.
- ☒ C. no change in velocity.
- D. no change in wavelength.

Common Weld Probes.

Shear Wave Probes or } Single Crystal
Angle " " } $45^\circ, 60^\circ, 70^\circ \rightarrow 4-5 \text{ MHz.}$

Normal Probes } Twin Crystal. $0^\circ \rightarrow 4-5 \text{ MHz.}$
Compression or 0° } Crystal diameter = $10 \rightarrow 15 \text{ mm.}$

14. The phenomenon whereby an ultrasonic wave changes direction when the wave crosses a boundary between materials with different velocities is called:

- ☒ A. refraction.
- B. reflection.
- C. penetration.
- D. rarefraction.

15. How many echoes would be present on the C.R.T. if a V1 (A2) block is used to calibrate a normal probe 0 to 50mm, on the 25mm dimension?

- ☒ A. 2.
- B. 4.
- C. 8.
- D. 16.

16. The 1.5mm hole in a V1 (A2) test block may be used to:

- A. determine the resolution of a probe.
- B. determine the pulse width.
- ☒ C. set the test sensitivity.
- ☒ D. All of the above.

17. An echo is set at full screen height on a vertically calibrated C.R.T. then the sound is reduced by 6dB:

- ☒ A. the echo will drop by 50% of its initial height.
- B. the echo will drop to 20% full screen height.
- C. the echo will probably disappear off the screen.
- D. the echo will drop to 10% full screen height.

18. What is the thickness of a V2 (A4) test block?

- ☒ A. 12.5mm.
- B. 20mm.
- ☒ C. Both the above are possible.
- D. 25mm.

19. What does 23mm of perspex represent in a V1 (A2) block when using compression probes?

- A. 100mm of steel
- B. 23mm of steel
- ☒ C. 50mm of steel
- D. 100mm of aluminium

20. Which of the following N.D.T. methods is the best to use on ferromagnetic materials?

- A. Magnetic particle testing.
- B. Radiographic testing.
- C. Ultrasonic testing.
- ☒ D. It depends on many factors, N.D.T. methods are usually complimentary.

21. Which of the following statements are true?

- ☒ A. The higher the probe frequency the faster the sound travels through a material.
- ☐ B. The higher the probe frequency the slower the sound travels through a material.
- ☒ C. The higher the frequency the more sound is lost due to attenuation losses.
- ☐ D. Immersion testing requires a grease based couplant.

22. Which wave type travels the fastest in steel?

- ☐ A. Longitudinal.
- ☒ B. Shear.
- ☐ C. Surface.
- ☐ D. Depends on the probe frequency.

23. Which of the following formulae is incorrect?

- ☐ A. $Nearzone = \frac{D^2}{4\lambda}$
- ☐ B. $\sin \theta = \frac{k\lambda}{D}$
- ☒ C. $Nearzone = \frac{D^2 \times f}{4 \times c}$
- ☒ D. $\sin \theta = \frac{K \times f}{D \times c}$

D = crystal diameter

λ = wavelength

$\theta = \frac{1}{2}$ angle

f = frequency

c = velocity

24. Which of the following formulae is incorrect?

- ☒ A. Half skip distance = wall thickness x tan of the probe angle
- ☐ B. $\sin = \frac{Opp}{Hyp}$
- ☒ C. $\lambda = \frac{f}{c}$
- ☐ D. $10\%half \angle = \frac{1.08 \times c}{D \times f}$

25. Sound attenuation in a material is due to:

- ☒ A. absorption and scattering.
- ☐ B. reflection and refraction.
- ☐ C. density and velocity.
- ☐ D. density and elasticity.

26. When the incident angle is chosen between the first and second critical angles, the ultrasonic waves generated in the test specimen will be:
- A. longitudinal.
 - ☒ B. shear.
 - C. surface.
 - D. Lamb.
27. Which British Standard relates to N.D.T. terms?
- A. BS 2704.
 - B. BS 2910.
 - C. BS 5996.
 - ☒ D. BS 3683.
28. Which of the following statements is true in relation to carrying out ultrasonic testing on a steel rectangular block using normal probes?
- A. It is possible to know the exact size of a defect by measuring the echo height.
 - B. It is possible to know the exact size of a defect by assessing the echo shape.
 - ☒ C. A small echo on the C.R.T. may be a large significant defect.
 - D. None of the above are true.
29. Calculate the wavelength for a frequency of 4.25MHz at a velocity of 5800 metres per second:
- A. 0.73mm.
 - ☒ B. 1.36mm.
 - C. 0.073mm.
 - D. 0.136mm
30. Of the following scan types, which produces a *plan view* of any defective areas under test?
- ☐ A. A-scan.
 - ☐ B. B-scan.
 - ☒ C. C-scan.
 - D. D-scan.
31. A smooth flat discontinuity whose major plane is perpendicular to the direction of sound propagation may be indicated by:
- A. an echo amplitude comparable in magnitude to the back surface reflection.
 - ☒ B. a complete loss of back surface reflection.
 - C. an echo amplitude larger in magnitude than the back surface reflection.
 - ☒ D. All of the above are possible.
32. Which of the following transducers produces the least beam spread in the far zone?
- A. 1MHz, 10mm diameter crystal.
 - ☒ B. 5MHz, 25mm diameter crystal.
 - C. 2MHz, 25mm diameter crystal.
 - D. 5MHz, 10mm diameter crystal.

33. Which is the British Standard for ultrasonic test blocks?
- ☒ A. BS 2704.
 - B. BS 2910.
 - C. BS 5996.
 - D. BS 6072.
34. Ultrasonic waves in a test material are:
- ☒ A. electromagnetic waves.
 - B. low voltage electrical fields.
 - C. radio waves.
 - ☒ D. mechanical vibrations.
35. When an incident ultrasonic wave impinges upon an interface of two materials with different acoustic impedance values at an angle other than normal to the surface, the wave may be:
- A. reflected.
 - B. refracted.
 - C. mode converted.
 - ☒ D. All of the above.
36. Which of the following single crystal probes would contain the thinnest crystal?
- A. A $2\frac{1}{2}$ MHz compression probe.
 - ☒ B. A 15 MHz compression probe.
 - C. A 5 MHz angle probe.
 - D. A 10 MHz angle probe.
37. Which of the following statements best defines refraction?
- A. The ability of an ultrasonic pulse to locate a small defect.
 - B. The ability of an ultrasonic pulse to show a small defect on the C.R.T.
 - C. The ability of an ultrasonic test to show the C.R.T. the separate signals from two or more defects lying in close proximity.
 - ☒ D. The deviation from the normal path of the beam due to different material velocities.
38. The velocity of sound waves is primarily dependent on:
- ☒ A. the pulse length.
 - B. the frequency.
 - ☒ C. the material in which the sound is being transmitted and the mode of vibration.
 - D. None of the above.
39. In immersion testing, the most commonly used couplant is:
- ☒ A. water.
 - B. oil.
 - C. glycerine.
 - D. alcohol.

BAD REPORT EXAMPLE 1

OBSCURE INSPECTION COMPANY

MAGNETIC PARTICLE INSPECTION REPORT

1. Test item:

Weld 21 and 22 on fabrication number 18A.

2. Weld details:

Material: Carbon steel

Weld process: MIG

Weld preparation: 60°

Root gap: 2.5 mm

3. Equipment:

Crack detection unit

Black magnetic ink

4. Test sensitivity:

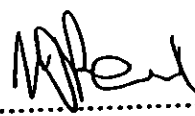
150 amps per inch of weld.

5. Test results:

- a. Two cracks 25 mm long; 60 mm from reference.
- b. One indication 10 mm long, 120 mm from reference.
- c. Irrelevant indication at six o'clock position on W22.

6. Action:

All defects to be removed by grinding and cleared by penetrant testing before re-welding.

SIGNED: 

DATE: 14/1/91

OBSCURER INSPECTION COMPANY

RADIOGRAPHIC TESTING REPORT

Test item: ~~Butt weld No. 654 in boiler tube, 50 mm x 6.35 mm.~~ Date, Job Number, Page & Report Number.

Butt weld No. 654 in boiler tube, 50 mm x 6.35 mm.

Weld information:

Material: Steel Not enough detail.

Weld process: MMA

Bevel angle: 70° Included or not.

Root gap: 1 mm No root face.

Test information:

Technique: No

Radiation type: X Rays

Isotope

Activity

Not Ir 192, Yb 167, for thickness

Exposure: 2 Mins 0 Sec

IQI type: Co 945 If steel not right IQI type.

Film type: None

Processing: Developer time (type) 4 MIN

Developer temp.

Fixer time (type)

Screen type.

No temp.

To high a time.

Batch + Manufacturer.

Test results: No techniques, etc.

Section Comments

Shot A Quality: Density 1.5% IQI type not present.

Defects: LOSWF 10 mm No datum, No sensitivity.

Shot B Quality: Density acceptable

Defects: Defect free No mention of IQIS.

Shot C Quality: Density 2.8-4.0 in the weld tungsten inclusions in an area 100 mm x 10 mm No datum, etc.

No standards, no technique.

Would advise defects to be repaired. Shot C to be resubmitted.

SIGNED:

B Jones B Jones

REPORT DATE:

14/1/91

No quals, etc

No Sensitivity

OBSCURE INSPECTION COMPANY

ULTRASONIC INSPECTION REPORT

1. Weld No.
Weld 234
2. Weld details:
 - Material: Stainless steel
 - Weld process: MMA
 - Weld angle: 60° Single vee
 - Root gap: 2 mm
3. Equipment:
 - Ultrasonic flaw detector
 - Calibration blocks to BS 3704
 - Couplant
 - Probes: 45 4MHz; 60 5MHz; 70 5MHz; 0 twin crystal.
4. Test sensitivity
 - Compression - 2nd BWE FSH
 - Shear - 1.5 mm hole in V1 FSH
5. Results
 - a. Two slag inclusions 50 mm x 3 mm, see sketch attached.
 - b. Crack 40 mm long on side wall A.
6. Action
 - All defects to be removed and checked by MPI before re-welding.
7. Comments:



REPORT EXAMPLE 4

OBSCURE INSPECTION COMPANY

ULTRASONIC INSPECTION REPORT

Report ref. no:	12345	Date of test:	10/6/92	Sheet 1 of 1
Work location: Lossof Power Station				
Ultrasonic test procedure applicable: A2121				
Defect acceptance/rejection criteria: BS 2633				
Weld identification: L2-W6		Material type: Low carbon steel		
Weld process: Tig root; mma fill & cap		Wall thickness: 20 mm		
Type of joint: Single vee; pipe to pipe		Weld preparation: 60° included angle 1.5 mm root face 1.5 mm root gap		
Ultrasonic test equipment type: Sonatest 110		Serial No. S45445		
Probes used:		Couplant: Glycerine		
Double compression	10 mm dia.	1 MHz	0°	Serial Number.
Single shear	10 mm dia.	5 MHz	45°	
Single shear	10 mm dia.	5 MHz	60°	
Single shear	10 mm dia.	5 MHz	85°	
Scanning patterns: to procedure No. A2121				
Sensitivity:		0° scanning: 2nd BWE Angle probe scanning: 1.5 mm hole		
Calibration: 100 mm range from A4 calibration block				
Report on test item:				
Acceptable to specification				
standard.				
Attenuation check.				
Sensitivity check.				
Name: J K Smith				
Signature: _____				
Date of test: _____				
Quals.				

REPORT EXAMPLE 5

OBSCURE INSPECTION COMPANY			
ULTRASONIC INSPECTION REPORT			
Report ref. no: 34	Date of test: 11/6/92	Sheet 1 of 1	
Work location: Lossof Power Station			
Ultrasonic test procedure applicable: A33			
Defect acceptance/rejection criteria: BS 2633			
Weld identification: Spool 7 W66		Material type: Low carbon steel	
Weld process: ~~Wrong Process~~ Mma root; tig fill & cap		Wall thickness: 25 mm	
Type of joint: Single vee <u>No item</u>		Weld preparation: 70° bevel angle ~~if included~~ . 2.0 mm root face 2.0 mm root gap	
Ultrasonic test equipment type: Krautkramer USK7 Serial No. KK445			
Probes used:		Couplant: Yes ; Type .	
Double shear	10 mm dia.	4 MHz	0°
Single comp. ~~Wrong Size~~	10 mm dia.	5 MHz	60°
Single comp.	10 mm dia.	5 MHz	70°
Scanning patterns: to standard ~~What standard.~~			
Sensitivity: 0° scanning: 2nd BWE to FSH ~~what.~~ Angle probe scanning: 1.5 mm hole from calibration block ~~what~~			
Calibration: 100 mm range from calibration block ~~what Block.~~			
Report on test item:			
Acceptable to specification			
~~what?~~ Attenuation check Post-clean.			
Name: B K Jones			
Signature:			
Date of test:			

17 REPORTING OF RESULTS

A report shall be prepared for every weld inspected. This report shall include the following information as a minimum:-

- (i) Client.
- (ii) Item number.
- (iii) Weld identification.
- (iv) Operator's name, signature and qualifications.
- (v) Date of test.
- (vi) Flaw detector used (including serial no.).
- (vii) Details of all probes used including all performance checks required by section 8 of this document.
- (viii) Reference and inspection sensitivities employed for each DAC curve.
- (ix) Details of all areas where the surface preparation is out of specification, including individual profile sketches.
- (x) All attenuation measurements and the resultant mean.
- (xi) Weld inspection designs for the various weld geometries, including areas of limited coverage due to surface flatness, parent material quality, geometry, or access problems.
- (xii) Details of all flaws which exceed the recording threshold (see section 16.4).
- (xiii) Where a flaw has been sized using probe movement techniques, it shall be shown on a full size cross-sectional drawing, indicating the through wall dimension of the flaw. A table of the stand-off and range measurements together with the stand-off datums shall be included.
- (xiv) Details of any restrictions to test.
- (xv) The position of any inspection datums used and the dimensions of the component under test (circumference, weld thickness).
- (xvi) The report number(s) of any complementary inspection reports (if known).
- (xvii) Flaw sizing technique.

18. ACCEPTANCE/REJECTION OF REPORTED INDICATIONS

All reported indications observed in new welds should be evaluated and sentenced in accordance with the relevant British Standard or Product Specification, i.e. BS 2633:1987 or BS 1113:1989 depending on location and type of welded component.

Table 10.* Numerical indication of process

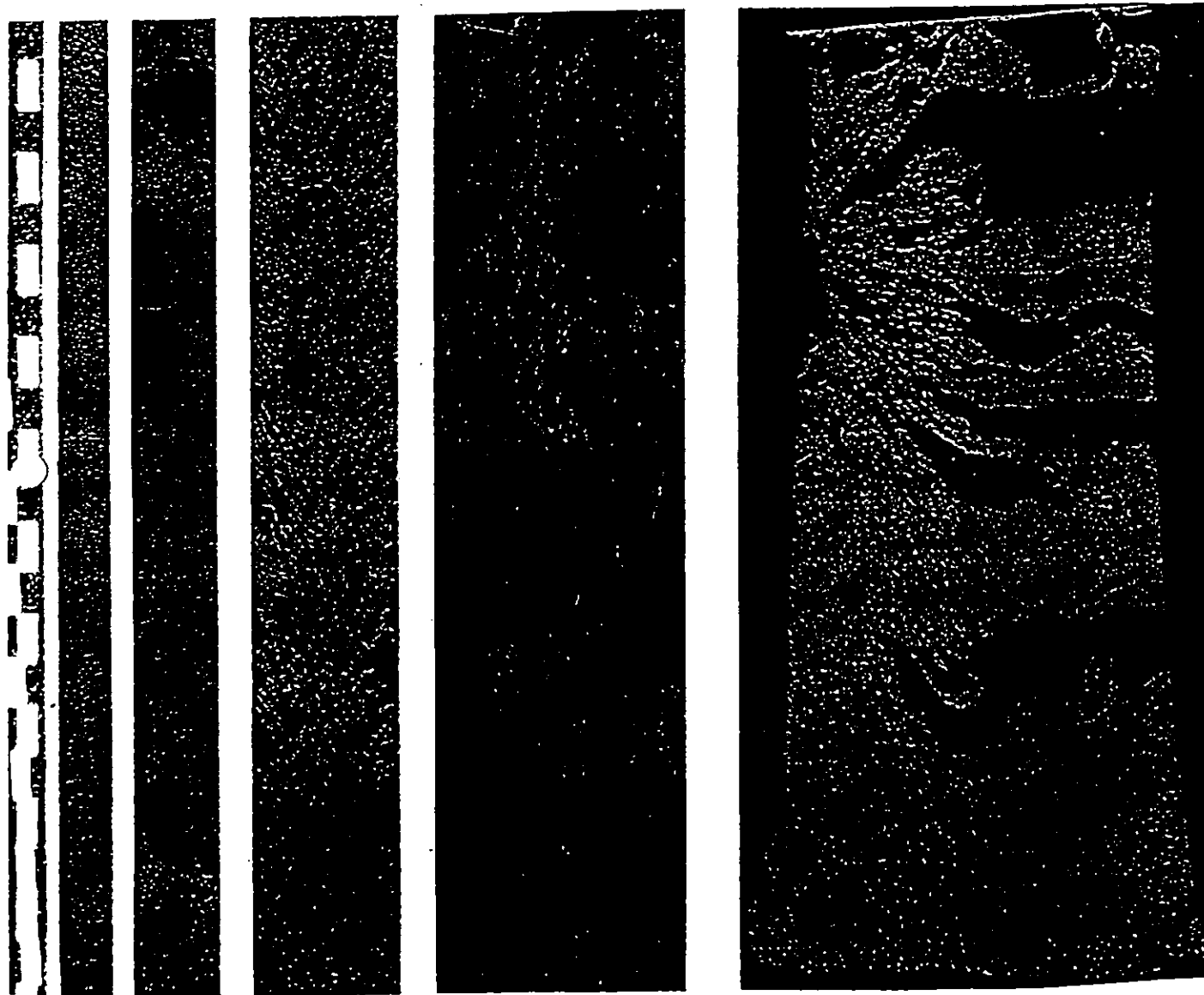
No.	Process	No.	Process
1	Arc welding	47	Gas pressure welding
11	Metal-arc welding without gas protection	48	Cold welding
111	Metal-arc welding with covered electrode	7	Other welding processes
112	Gravity arc welding with covered electrode	71	Thermit welding
113	Bare wire metal arc welding	72	Electroslag welding
114	Flux cored metal-arc welding	73	Electrogas welding
115	Coated wire metal-arc welding	74	Induction welding
118	Firecracker welding	75	Light radiation welding
12	Submerged arc welding	751	Laser welding
121	Submerged arc welding with wire electrode	752	Arc image welding
122	Submerged arc welding with strip electrode	753	Infrared welding
13	Gas shielded metal-arc welding	76	Electron beam welding
131	MIG welding	77	Percussion welding
135	MAG welding metal-arc welding with non-inert gas shield	78	Stud welding
136	Flux cored metal-arc welding with non-inert gas shield	781	Arc stud welding
14	Gas-shielded welding with non-consumable electrode	782	Resistance stud welding
141	TIG welding	9	Brazing, soldering and braze welding
149	Atomic-hydrogen welding	91	Brazing
15	Plasma arc welding	911	Infrared brazing
18	Other arc welding processes	912	Flame brazing
181	Carbon arc welding	913	Furnace brazing
185	Rotating arc welding	914	Dip brazing
2	Resistance welding	915	Salt bath brazing
21	Spot welding	916	Induction brazing
22	Seam welding	917	Ultrasonic brazing
221	Lap seam welding	918	Resistance brazing
225	Seam welding with strip	919	Diffusion brazing
23	Projection welding	923	Friction brazing
24	Flash welding	924	Vacuum brazing
25	Resistance butt welding	93	Other brazing processes
29	Other resistance welding processes	94	Soldering
291	HF resistance welding	941	Infrared soldering
3	Gas welding	942	Flame soldering
31	Oxy-fuel gas welding	943	Furnace soldering
311	Oxy-acetylene welding	944	Dip soldering
312	Oxy-propane welding	945	Salt bath soldering
313	Oxy-hydrogen welding	946	Induction soldering
32	Air fuel gas welding	947	Ultrasonic soldering
321	Air-acetylene welding	948	Resistance soldering
322	Air-propane welding	949	Diffusion soldering
4	Solid phase welding; Pressure welding	951	Flow soldering
41	Ultrasonic welding	952	Soldering with soldering iron
42	Friction welding	953	Friction soldering
43	Forge welding	954	Vacuum soldering
44	Welding by high mechanical energy	96	Other soldering processes
441	Explosive welding	97	Braze welding
45	Diffusion welding	971	Gas braze welding
		972	Arc braze welding

* This table complies with International Standard ISO 4063

Table 1
Designation of Welding and Allied Processes by Letters

Welding and allied processes	Letter designation	Welding and allied processes	Letter designation
diffusion bonding	ABD	induction	RSEW-I
resistance welding	AW	resistance spot welding	RSW
atomic hydrogen welding	AHW	upset welding	UW
bare metal arc welding	BMAW	high frequency induction	UW-HF
carbon arc welding	CAW		UW-I
gas	CAW-G	soldering	S
shielded	CAW-S	dip soldering	DS
twin	CAW-T	furnace soldering	FS
electrode gas	EGW	induction soldering	IS
flux cored arc welding	FCAW	infrared soldering	IRS
gas metal arc welding	GMAW	iron soldering	INS
pulsed arc	GMAW-P	resistance soldering	RS
short circuiting arc	GMAW-S	torch soldering	TS
gas tungsten arc welding	GTAW	wave soldering	WS
pulsed arc	GTAW-P	solid-state welding	SSW
plasma arc welding	PAW	coextrusion welding	CEW
shielded metal arc welding	SMAW	cold welding	CW
stud arc welding	SW	diffusion welding	DFW
submerged arc welding	SAW	explosion welding	EXW
series	SAW-S	forge welding	FW
friction welding	B	friction welding	FRW
arc brazing	AB	hot pressure welding	HPW
block brazing	BB	roll welding	ROW
carbon arc brazing	CAB	ultrasonic welding	USW
diffusion brazing	DFB	thermal cutting	TC
dip brazing	DB	arc cutting	AC
flow brazing	FLB	air carbon arc cutting	AAC
furnace brazing	FB	carbon arc cutting	CAC
induction brazing	IB	gas metal arc cutting	GMAC
infrared brazing	IRB	gas tungsten arc cutting	GTAC
resistance brazing	RB	metal arc cutting	MAC
torch brazing	TB	plasma arc cutting	PAC
thermal welding processes		shielded metal arc cutting	SMAC
electron beam welding	EBW	electron beam cutting	EBC
high vacuum	EBW-HV	laser beam cutting	LBC
medium vacuum	EBW-MV	air	LBC-A
nonvacuum	EBW-NV	evaporative	LBC-EV
electroslag welding	ESW	inert gas	LBC-IG
flow welding	FLOW	oxygen	LBC-O
induction welding	IW	oxygen cutting	OC
laser beam welding	LBW	chemical flux cutting	FOC
thermit welding	TW	metal powder cutting	POC
oxy-fuel gas welding	OFW	oxyfuel gas cutting	OFC
acetylene welding	AAW	oxyacetylene cutting	OFC-A
oxyacetylene welding	OAW	oxyhydrogen cutting	OFC-H
oxyhydrogen welding	OHW	oxynatural gas cutting	OFC-N
pressure gas welding	PGW	oxypropane cutting	OFC-P
resistance welding	RW	oxygen arc cutting	AOC
flash welding	FW	oxygen lance cutting	LOC
percussion welding	PEW	thermal spraying	THSP
projection welding	PW	arc spraying	ASP
resistance seam welding	RSEW	flame spraying	FLSP
high frequency	RSEW-HF	plasma spraying	PSP

FRACTURE SURFACE REPLICAS



THE WELDING INSTITUTE

Fracture Surface Replicas

Introduction

Fatigue and Brittle Fracture are the two most important forms of service failure in welded structures; the former, because it accounts for more than 90% of all service failures and the latter because, although rare in occurrence, brittle fractures are usually catastrophic particularly in economic terms, and can also cause loss of life. The accompanying set of fracture surface replicas shows examples of these two modes of failure. There are four examples of each mode, and the notes which follow describe the fracture surfaces in detail, drawing attention to those features of the fracture surface that are particularly helpful in interpretation. Whilst all but two of the surfaces illustrated are from failures of laboratory specimens, the essential features are similar to those that would be observed in service failures.

Fatigue Fracture Surfaces (Nos. 1-4)

Fatigue is a form of structural failure caused by the action of fluctuating stress. It occurs at general stresses below the yield stress of the material used, and initiates at some form of stress concentration in the structure. In welded structures such stress concentrations arise either as a result of the external geometry of the weld or as internal discontinuities in the form of weld defects. The collection includes four fatigue fractures covering the principal types of stress concentration which can be anticipated in welded joints. Two of the fracture surfaces are those associated with typical design details and two with common internal defects. The two design details are a non-load-carrying fillet weld and a butt weld, both transverse to the applied stress. (Note, however, that welds parallel to the applied stress also create stress concentrations, either at the ends of discontinuous welds or at surface and root irregularities in continuous welds.) The failures initiating from internal defects illustrate a failure from slag inclusions in a butt weld, and a failure from a small pore in a shaft which

had been repaired by welding. The four failures are described in detail below. Reference 1 provides one of the best general introductions to the fatigue of welded structures.

Brittle Fracture Surfaces (Nos. 5-8)

Brittle fractures in steel structures usually occur without visible or audible warning at stresses less than the nominal yield stress. Such fractures usually initiate at sharp notches or crack-like defects and may subsequently propagate through a complete structure, the crack fronts travelling at several times the speed of sound in air. For most lower strength structural steels, the fracture surfaces tend to have a bright crystalline appearance resulting from cleavage in the microstructure, but in high yield strength alloy steels, the fracture surfaces often appear relatively dull, corresponding to very fine cleavage facets or fine dimpling, due to the formation and coalescence of small voids during fracture.

Three conditions are necessary before a brittle fracture can occur. These are a defect (usually a crack), a tensile stress transverse to the defect and a microstructure which is susceptible at the temperature of interest. Structural steels display transitional behaviour from brittle cleavage fracture to ductile fracture with increasing temperature. The temperature at which this transition occurs is influenced by material thickness. Thicker sections enable a higher degree of triaxial stress to be maintained at crack tips, and for this reason they remain brittle at higher temperatures than thinner sections.

Four brittle fracture specimens are included in the collection, two of which have been taken from service failures investigated at The Welding Institute. The other two fractures are from specimens of a type used in the laboratory to assess fracture toughness and show the difference in fracture behaviour of a particular material at two temperatures.

References

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"Fatigue of welded structures"
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Proceeding of the Conference on Fatigue of Welded Structures, The Welding Institute 1971.
3. Newman, R. P. and Gurney, T. R.
"Fatigue tests on plain plate specimens and transverse butt welds"
British Welding Journal, Vol. 6, No. 12, 1959, pp. 569-594.
4. Harrison, J. D., Burdekin, F. M. and Young, J. G.
"A proposed acceptance standard for weld defects based upon suitability for service"
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5. Dawes, M. G.
"The fatigue strengths of ferritic steel shafts reclaimed by welding and metal spraying"
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6. "Tentative method to test for plane strain fracture toughness in metallic materials". A.S.T.M. Designation E 399-70T.
7. "Methods for plane strain fracture toughness (K_{Ic}) testing"
Draft British Standards Document, DD3: 1971.

Fracture Surface No. 1

fatigue initiating from the toe of a transverse load-carrying fillet weld

It is virtually impossible to design a complex welded structure without fillet welds. Due to their shape, and the presence of small defects (2) at the weld toe (Figure 1) these constitute severe stress raisers, either across the plate where the stress is transverse to the weld, or at the weld end for welds parallel to the direction of stressing. Consequently, the fatigue strengths of many welded structures are affected by the unavoidable presence of fillet welds. The fracture surface is typical of that commonly observed in the case of transverse non-load-carrying fillet welds. Figure 2 shows the S-N curve from the series of which this specimen was part, and the actual test result for the specimen is indicated by an arrow in the diagram.

Points to note on the fracture surface (Figure 3) are that the fatigue failure has initiated at the toes of the welds on the two opposite surfaces of the load-carrying plate and that it has initiated at a number of points along these weld toes (a, b, c, d and p, q, r). These separately initiated fatigue cracks on each side have been joined up by steps in the fracture surface more or less perpendicular to its plane. Once the separately initiated cracks on each side had joined up, the fatigue cracks on the two opposite sides of the

specimen grew in an approximately semi-elliptical fashion until they, in turn, eventually joined up in a similar fashion by shear lips (Figure 4). The final ductile fracture (X) represents a relatively small proportion of the overall area of the fracture surface. Scanning electron microscopy of the flatter features of the fracture surface would show the individual fatigue striations associated with each cycle of loading. The shiny regions at each end of the load-carrying section were caused by the two broken halves hammering together immediately after failure (i.e. before the testing machine had stopped).

Other features to note are the surface ripples of the weld beads, which indicate that each weld was made in two passes, each starting from one of the ends of the non-load-carrying attachment and being deposited towards the centre, where the smooth circular stop position of the second weld bead can be seen (F). Both surface ripples and start and stop positions can provide easy initiation sites for fatigue failure if suitably oriented with respect to the stress system. Note particularly the undercut at G which would have provided a particularly good initiation site for fatigue in this specimen, if it had occurred on the other side of the weld bead.

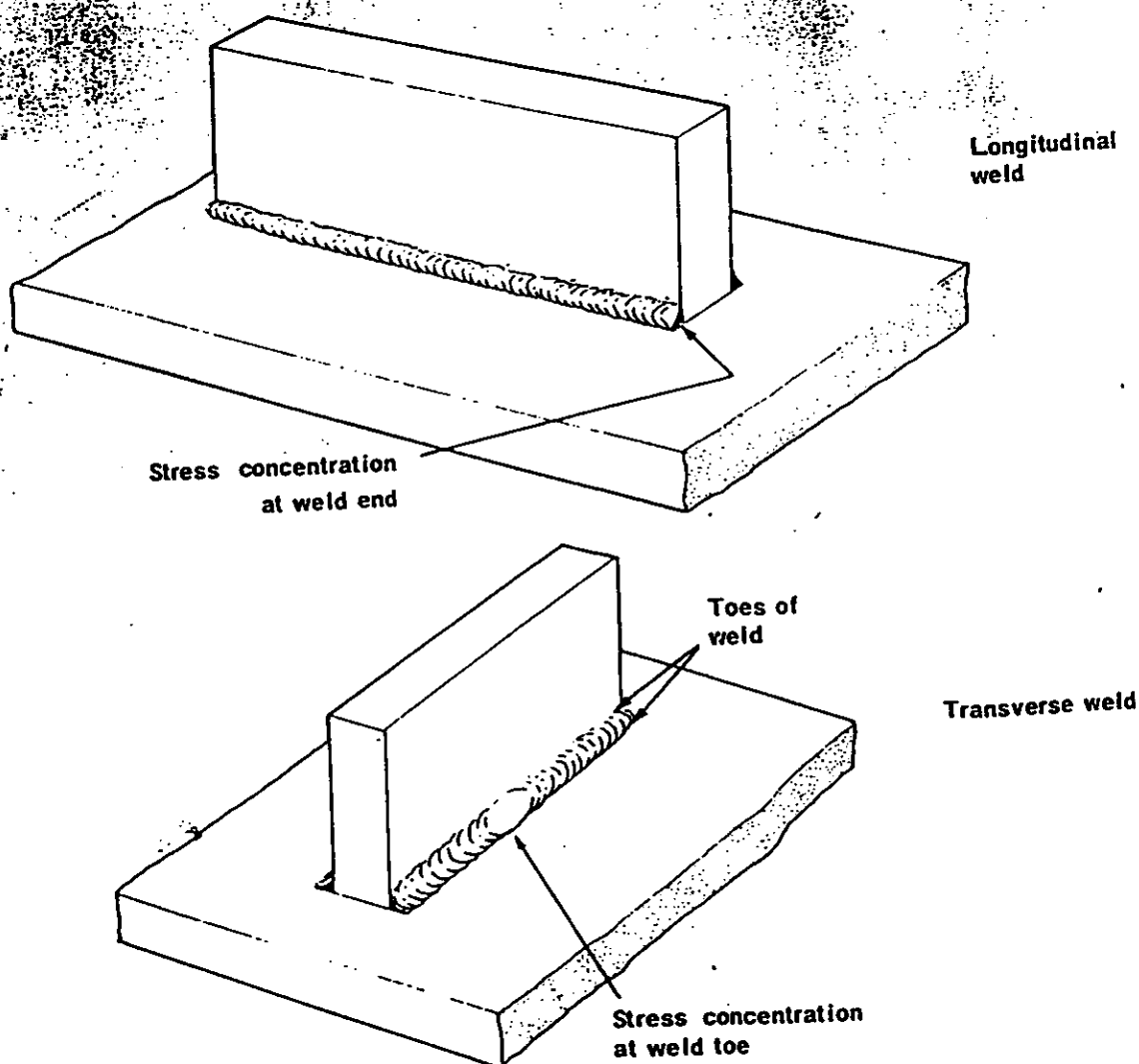


Fig. 1 Non-load-carrying fillet welds.

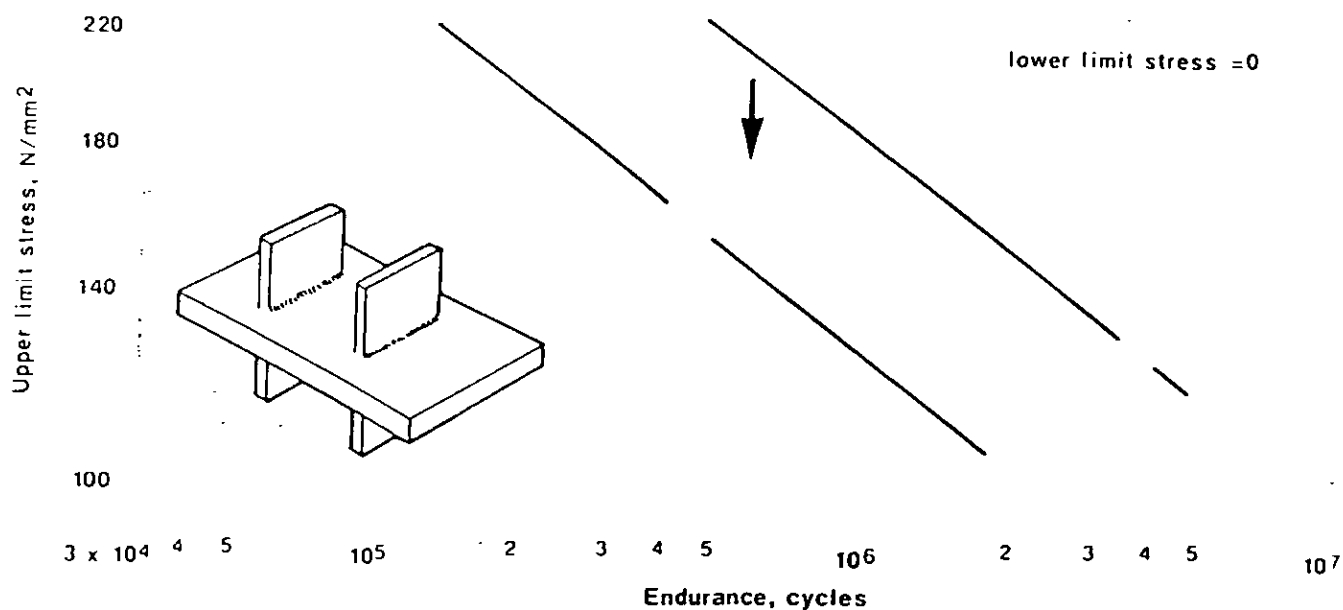


Fig 2 S-N curve for transverse non-load-carrying fillet welds.

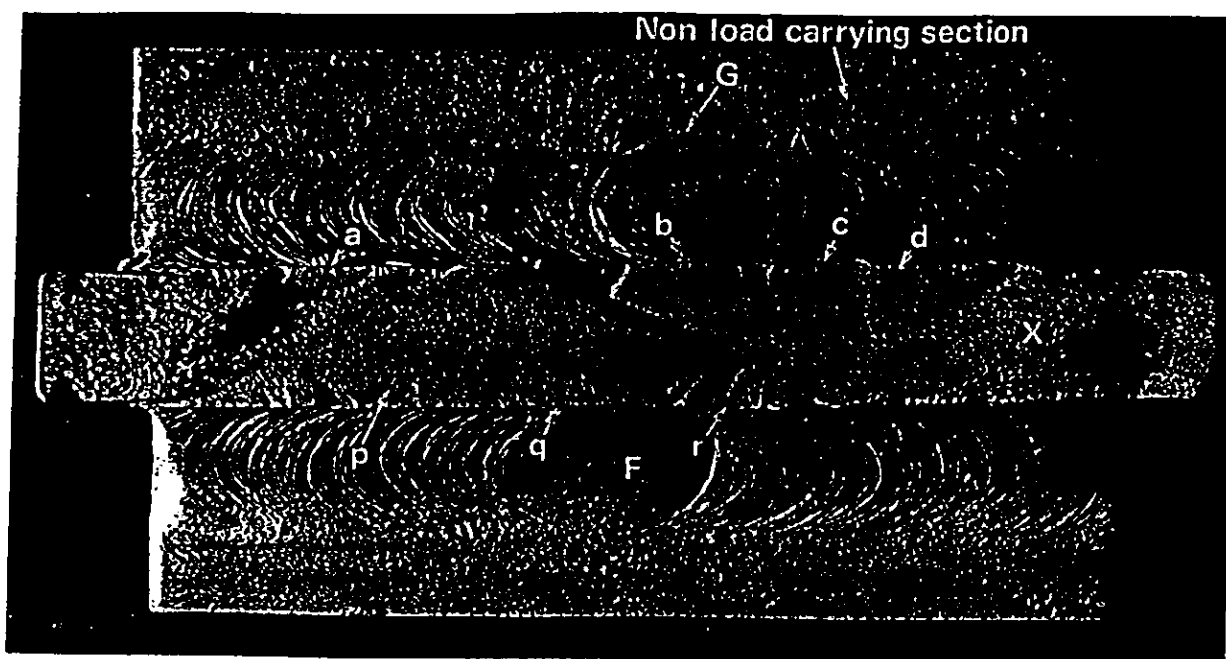


Fig 3 Fatigue fracture initiated at a transverse non-load-carrying fillet weld.

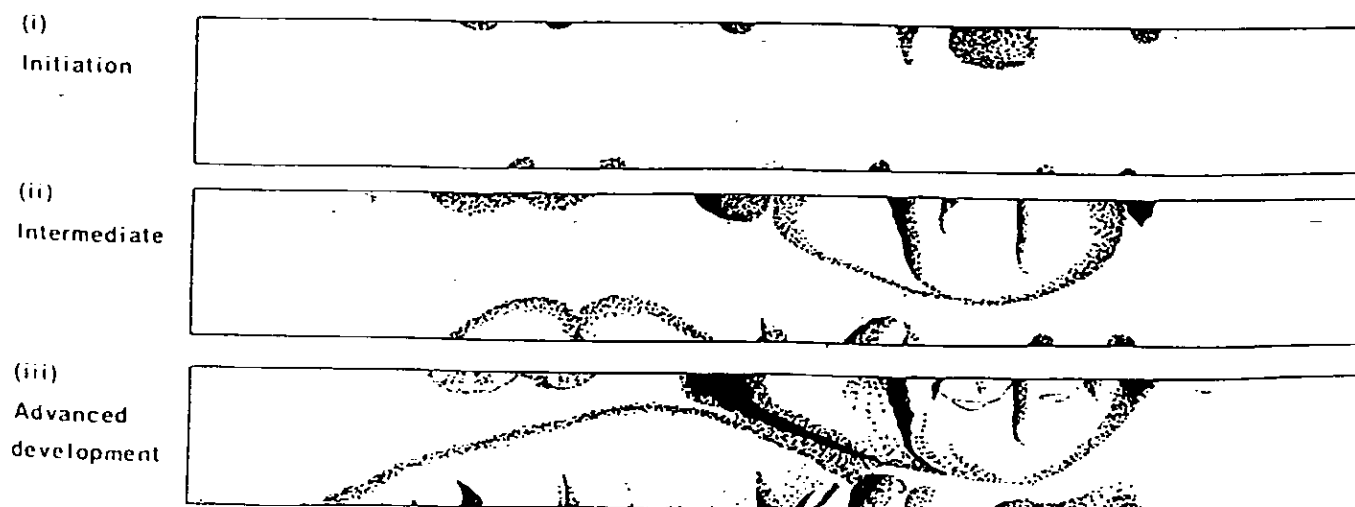


Fig 4 Schematic indication of the initiation and growth of fatigue cracks to form the surface shown in Fig. 3.

Fracture Surface No. 2

Fatigue initiating at the edge of a transverse butt weld

A perfect butt weld whose surface is flush with the plate surface should have very little stress concentrating effect, but in practice, because excess metal is deposited, the fatigue strength of transverse butt welds is critically dependent on the weld profile (3). Strengths at 2 million cycles can vary between 75 and 190 N/mm² and although the profile can be improved by grinding, commercially this is very expensive.

The sample in the collection is of a butt weld (Figure 5), deposited using an automatic welding process, in this case submerged-arc welding. An S-N curve for this type of joint is shown in Figure 6, and again the result for the actual specimen is indicated. Automatic welding produces a very uniform weld toe profile and it is of interest to observe on the fracture surface (Figure 5) that fatigue crack initiation has taken place over almost the entire length of one side of the specimen (A-A'). Also, because of the uniform

nature of the weld toe, the crack has initiated almost entirely on one plane and such stepping as occurs (B, C) between separately initiated cracks is far less marked than in the case of the fillet weld described above which was made using the manual metal-arc process. The applied stress range in this specimen was less than half the yield stress of the plate material so that the fatigue crack could propagate almost entirely through the section before failure occurred with the formation of the very small shear lips (D). Other features of interest on the fracture surface are the opening up of inclusions (E, F) in the rolling plane of the plate material at the extremities of the fatigue crack, just before final fracture. This delamination was caused by the extensive strain occurring at the crack tip as final failure started, and is not confined to fatigue fractures.

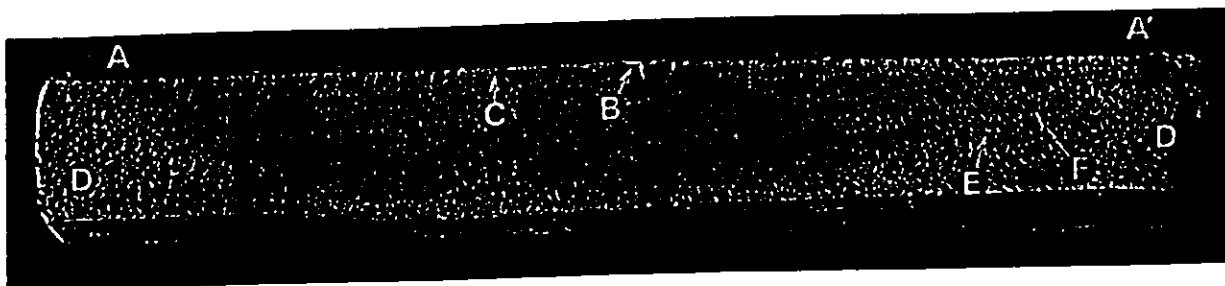


Fig. 5 Fatigue fracture initiated at the edge of a transverse butt weld.

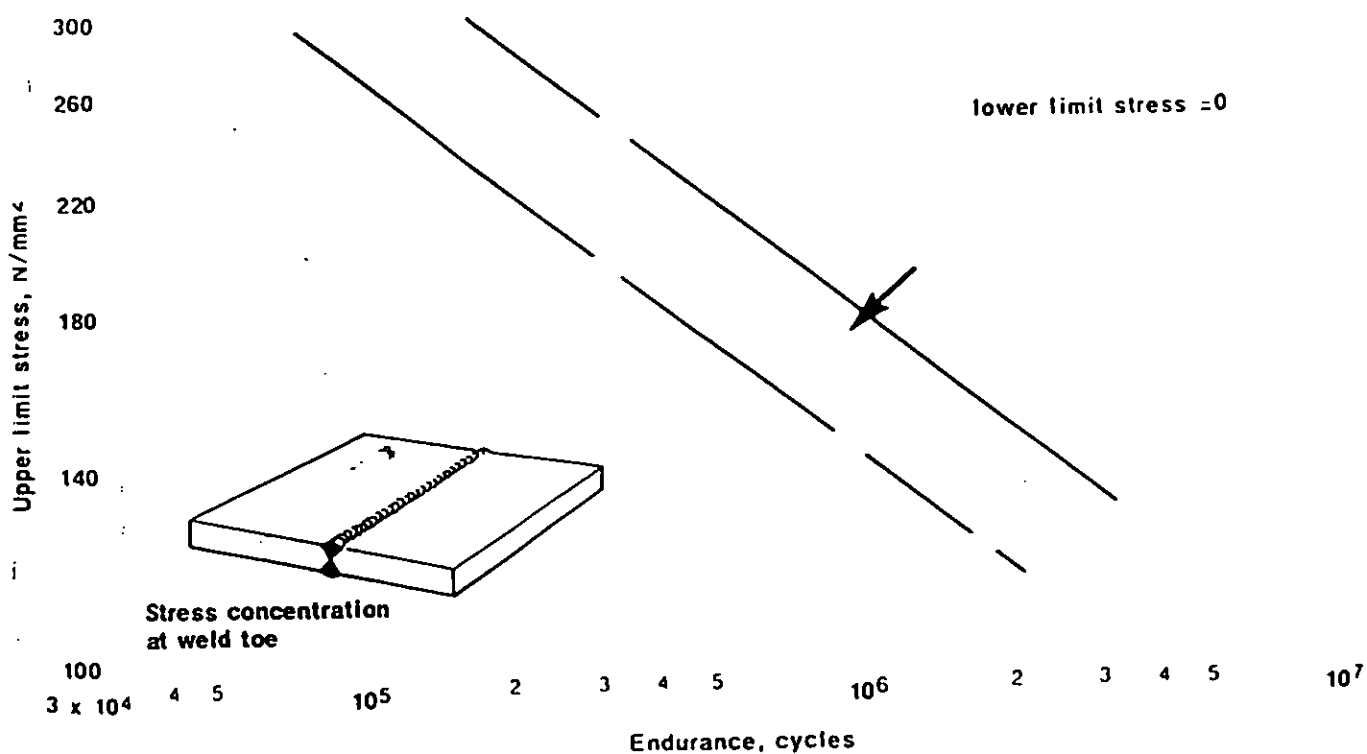


Fig. 6 S-N curve for transverse butt welds.

Fracture Surface No 3

Fatigue failure from buried slag inclusions

Internal defects which can be found by radiography or ultrasonics give rise to considerable discussion between inspecting authorities and fabricators. Nevertheless, research work carried out at The Welding Institute and elsewhere throughout the world has shown that, in many instances, internal defects are less harmful from the view-point of fatigue, than the typical design details which are essential to all welded structures, such as the fillet and butt weld referred to above.

The example given is one from a series of tests on 38mm thick butt welds, and contained three 6mm long slag inclusions (A, B and C in Figure 7). The results of this test series are shown in the form of an S-N diagram in Figure 8 where the experimental point corresponding to this specimen is arrowed. All three inclusions have initiated fatigue cracks, and in spite of the fact that the original inclusions were elongated, the fatigue cracks developed into a more or less circular configuration. This is entirely consistent with the predictions of fracture mechanics which show that the strain along the front of an advancing crack in an infinite medium is uniform only when its shape is circular. The effects of the edges of finite members in real structures may modify this shape slightly. Note the shear steps D and E between cracks initiated at different points of the inclusions and the very flat nature of the cracks in their early

stages of propagation. Towards the end of fatigue crack propagation, before final failure, radial markings are visible. These result from the higher local strains at this late stage of propagation, forcing the crack along preferred paths of weakness in the micro-structure. These advance tongues of fracture whose planes are not quite identical, join up shortly behind the advancing crack front to leave the radial undulations.

It is of interest to compare the fatigue strength indicated by the S-N diagram of 140 N/mm^2 (9 tonf/in^2) at 2 million cycles for this defective butt weld with the fatigue strength at the same endurance time for the fillet welded joint (Figure 2) of 125 N/mm^2 (8 tonf/in^2). It should be noted, however that this strength is high compared with that obtained for most types of fillet welded joints—typically a non-load-carrying fillet weld will give a strength of 5–6 tonf/in^2 for an endurance of 2×10^7 cycles. The conclusion from this comparison is that a structure containing the fillet weld as a design detail, with close to it a butt weld containing the unintentional defects, would fail preferentially from the fillet weld. Thus, in such a structure it would be unnecessary to carry out any repair welding for defects of the type under consideration. Investigations of this type have led to proposals for an acceptance standard for weld defects in structures subjected to fatigue loading (4).

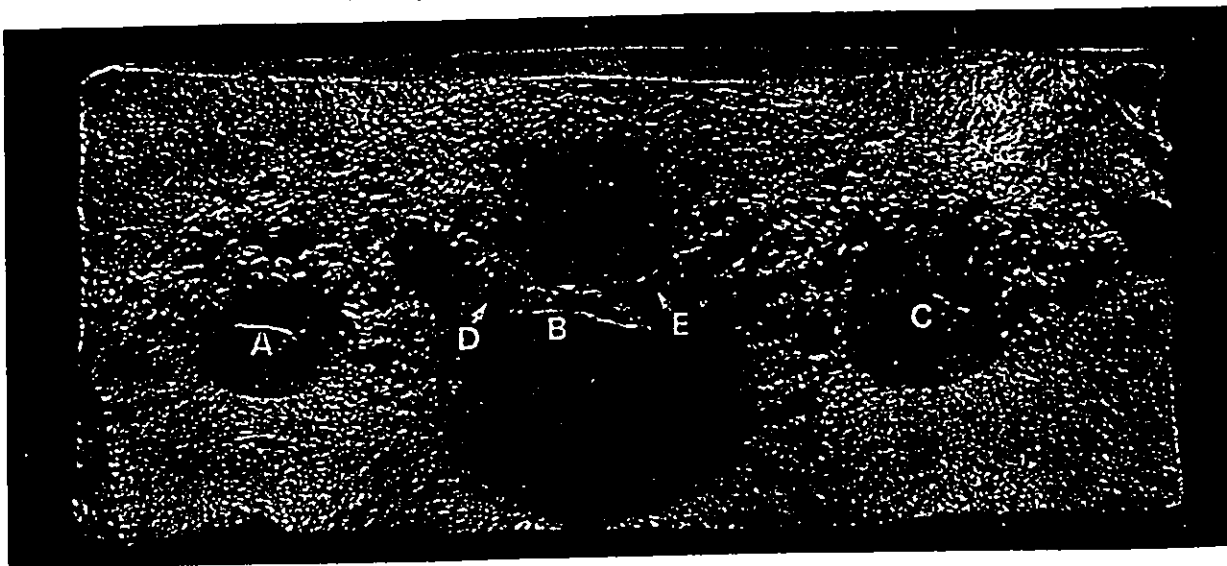


Fig. 7 Fatigue fracture initiated at internal weld defects.

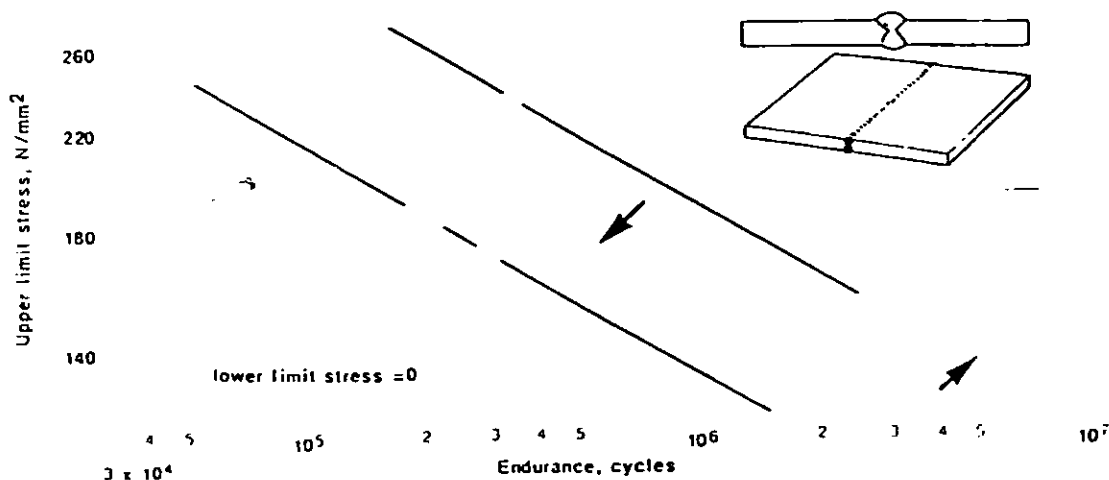


Fig. 8 S-N curve for 38mm thick butt welds containing 6mm long internal defects.

Fracture Surface No. 4

Fatigue of a shaft built up by welding

When the journals of crank and propeller shafts become worn it is common practice to build them up by various welding techniques and re-machine them to the original diameter. Since such shafts are normally designed on a basis requiring the elimination of mechanical stress raisers, weld defects in the building up layers become the most severe stress raisers present (5). In such components, even very small weld defects are capable of initiating fatigue cracks and it is generally observed that the fatigue strength of welded shafts is rarely more than 70% of that of the original unrepaired shaft.

The sample in the collection (Figure 9) shows a

fatigue failure initiated from a small pore (P) near the surface in the deposited layer. (Note also the region of ductile failure, Q, and the shear lips R, S and T formed as the two halves separated.) The S-N diagram for reclaimed shafts is shown in Figure 10 where the experimental point for this specimen is indicated. This is an example of a situation where, by the careful elimination of other stress raisers, small internal weld defects become most important, and it emphasises the fact that the significance of any given type of weld defect should be considered only in relation to the actual service requirements of the structure in which it exists.

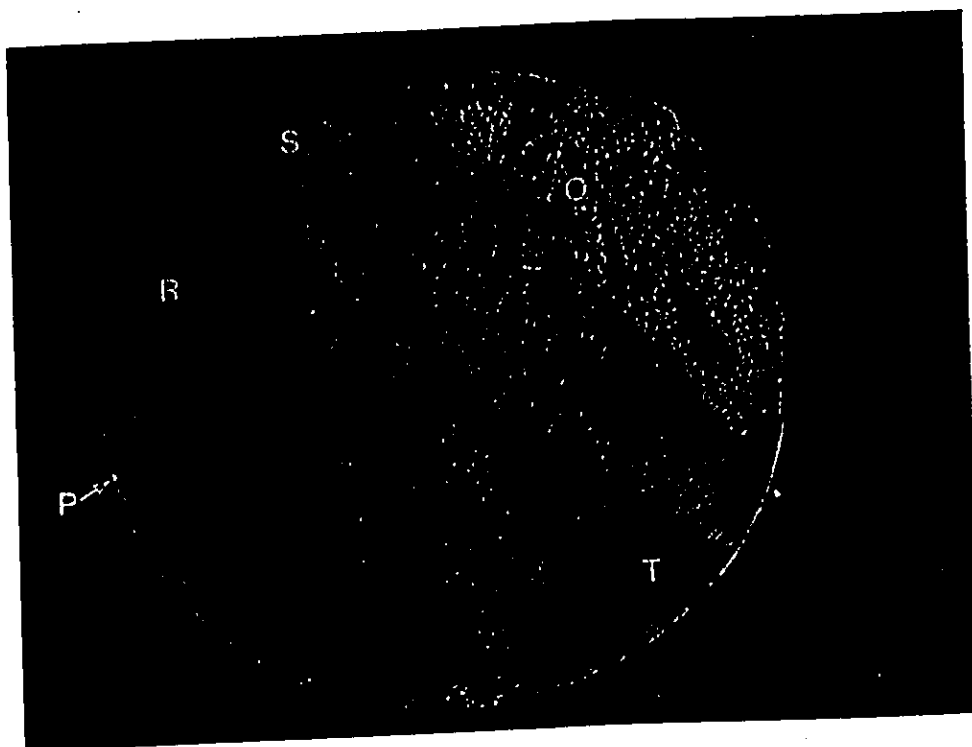


Fig. 9 Fatigue fracture initiated from a pore near the surface of a shaft built up by welding.

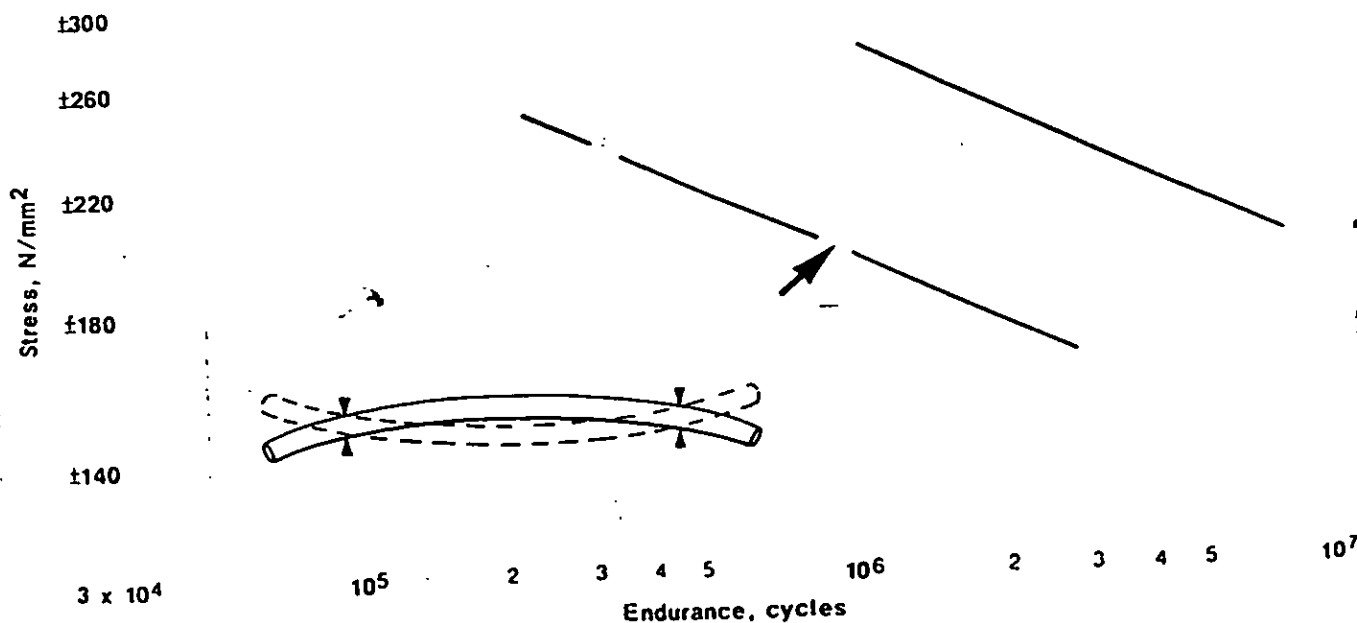


Fig. 10 S-N curve for shafts reclaimed by welding.

Fracture Surface No. 5

Fracture initiation region of a brittle fracture

This surface (Fig. 11) shows a number of features that are typical of brittle fractures in welded steel structures. The fracture started or initiated, from a semi-elliptical surface crack (C) at the edge of a butt weld. It will be noted that, except for a relatively small 45° shear lip along one surface (D), the fracture plane is at approximately 90° to the plate surfaces. A particularly striking feature of the fracture surface is the pattern of markings or striations which radiate from the surface crack. These are particularly important since they point back towards the origin of the fracture, thus allowing the point of initiation to be traced. Other features of interest are shear lips such as occur at points E and F. As on the fatigue fracture surfaces

discussed earlier, these shear lips are formed when two advancing tongues of fracture which do not lie in the same plane, are forced to join up. The reason why a fracture which started in one plane subsequently split into several planes, probably lies in the action of complex stress patterns ahead of the advancing crack.

A less important but interesting feature of this fracture surface is that the crack has propagated into the thicker material to the left of the weld defect. This behaviour reflects the tendency in common structural steels for resistance to crack propagation to decrease with increasing section thickness, because of the increase in triaxiality.

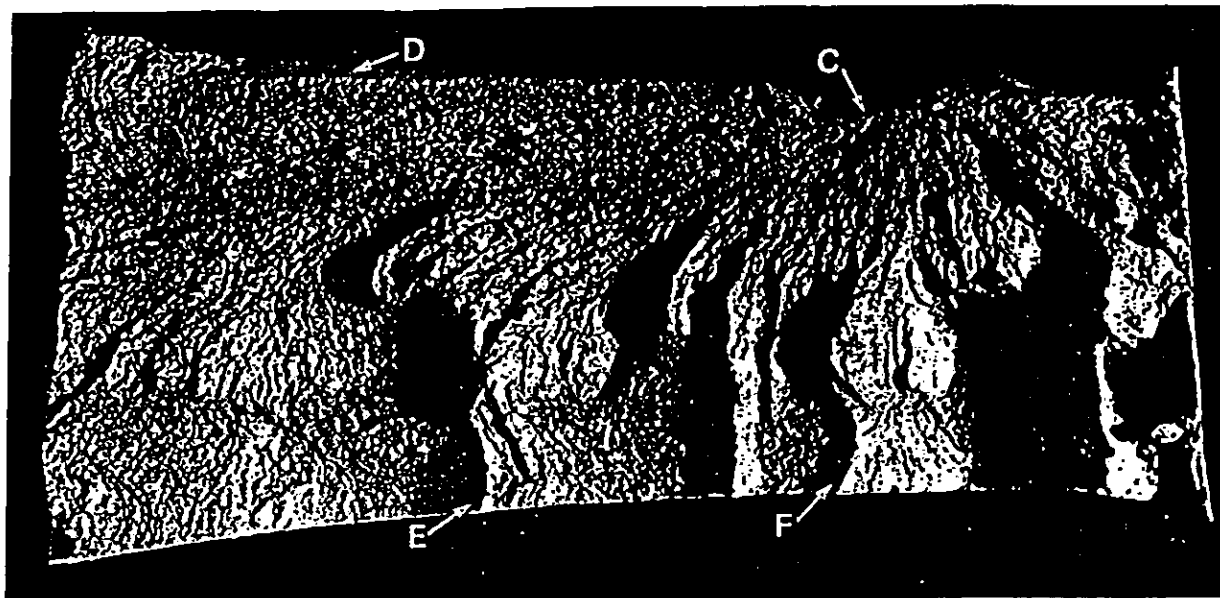


Fig. 11 Brittle fracture surface showing region of fracture initiation.

Fracture Surface No. 6

Fracture propagation region of a brittle fracture

This is part of a service fracture remote from the region of fracture initiation and shows characteristics typical of a propagating crack (Fig. 12). Note the small shear lips along both plate surfaces, indicating that the effective stresses in this instance were uniform across the plate thickness and that the fracture was very brittle. It will also be observed that the surface markings have become more uniform and exhibit

what is generally known as a 'herringbone' or 'chevron' pattern, which point like a series of arrows back towards the origin of the fracture. Clearly such fracture surface characteristics are extremely important in investigations of service failures, since they indicate the direction of travel of fracture and allow the region of fracture initiation to be traced.

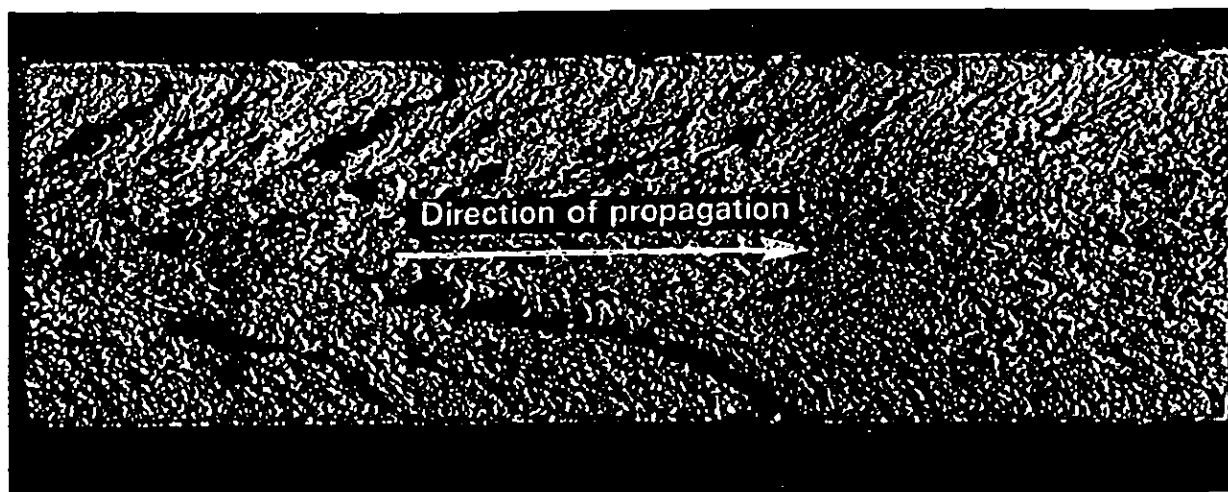


Fig. 12 Brittle fracture surface showing region of last fracture propagation

Fracture Surfaces Nos. 7 and 8

Laboratory Fracture Toughness Tests

These were obtained from single edge notched bend (SENB) tests on mild steel plate. The specimens were used for these tests complied with the design requirements for linear elastic fracture mechanics test pieces (6, 7). The fractures in these specimens (Figure 13) initiated from artificially induced defects that were made by machine notching and fatigue cracking the specimens before testing. The extent of the fatigue crack is shown by the very rough fracture surface (F) below the machined notch tip. The purpose of the fatigue crack was to produce a sharp natural crack tip. This is important because resistance to fracture is affected by notch geometry, i.e. sharp crack-like defects decrease resistance to fracture, and it must be remembered that brittle fractures initiate from sharp cracks.

A number of other variables also affect resistance to brittle fracture. For example, a decrease in temperature usually makes structural and pressure vessel steels more brittle. Thus, by making tests over a range of temperatures it is possible to demonstrate the change from a low toughness (very brittle) to a high toughness (very ductile) fracture. Figure 14 shows the results of some SENB fracture mechanics tests and indicates the relative fracture toughness of a specimen tested at a temperature where the steel was brittle (Figure 13a) and a similar specimen tested at a

temperature where the steel was tough (Figure 13b). In the case of the specimen tested at a low temperature (Figure 13a), the poor resistance to cleavage at this temperature resulted in a comparatively flat fracture, normal to the plate surfaces, with just the faintest evidence of a shear lip along the edges of the fracture. In contrast, the specimen tested at room temperature (Figure 13b) shows a flat central region with very extensive 45° shear lips at the sides of the specimen. The reason for this is that in the centre of the specimen a triaxial stress system developed which caused a flat fracture normal to the major stress direction. However, at the sides of the specimen, stresses normal to the surface could not be supported and yielding occurred. The resultant biaxial stress system then allowed shear to occur along planes at 45° to the plate surface. The relaxation of the third stress component normal to the sides of the specimen was caused by plastic deformation at the surface, as evidenced by a small contraction across the width of the specimen immediately below the fatigue crack tip. Because these tests were carried out in three-point bending, a large region of shear fracture also developed from the base of this specimen where compressive stresses were induced by the applied bending stress and the reaction stress from the anvil.

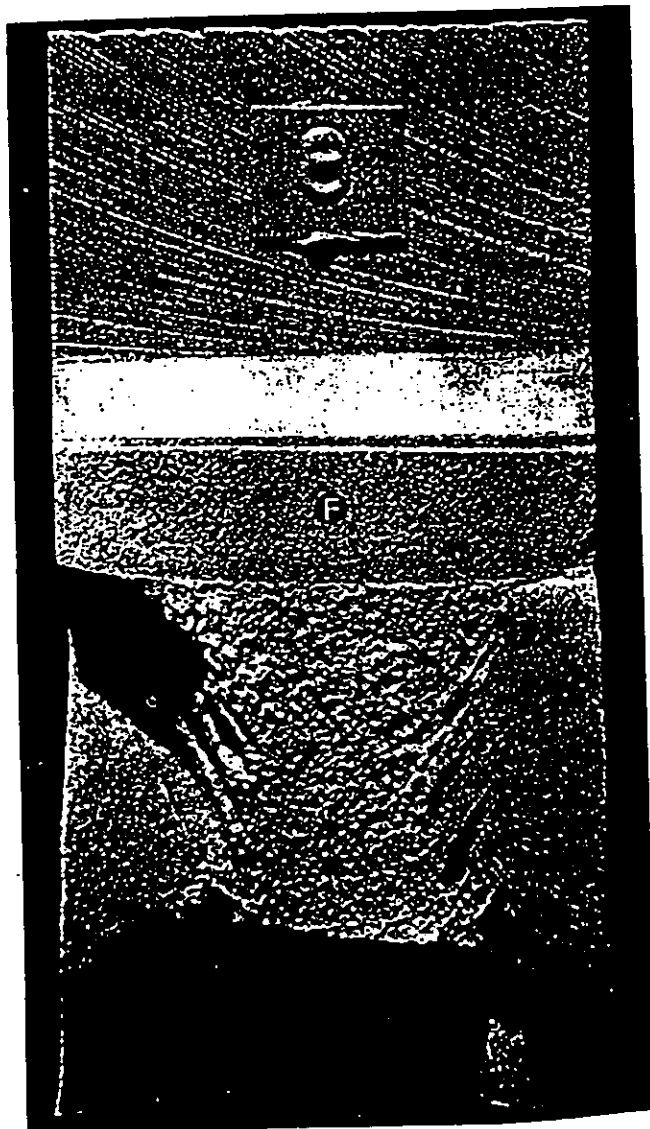
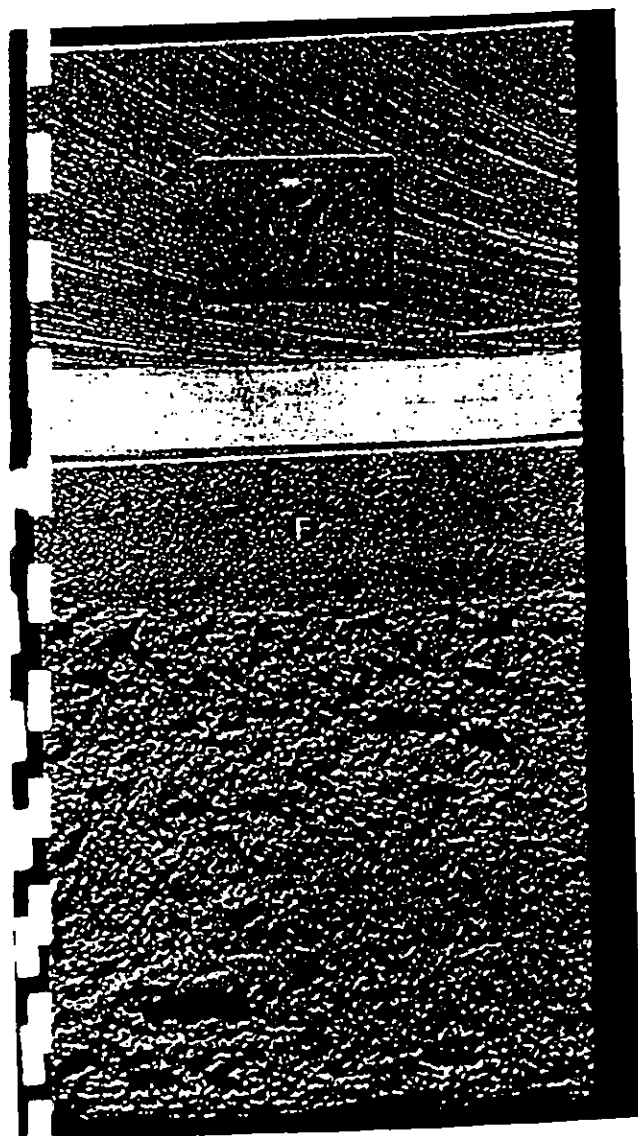
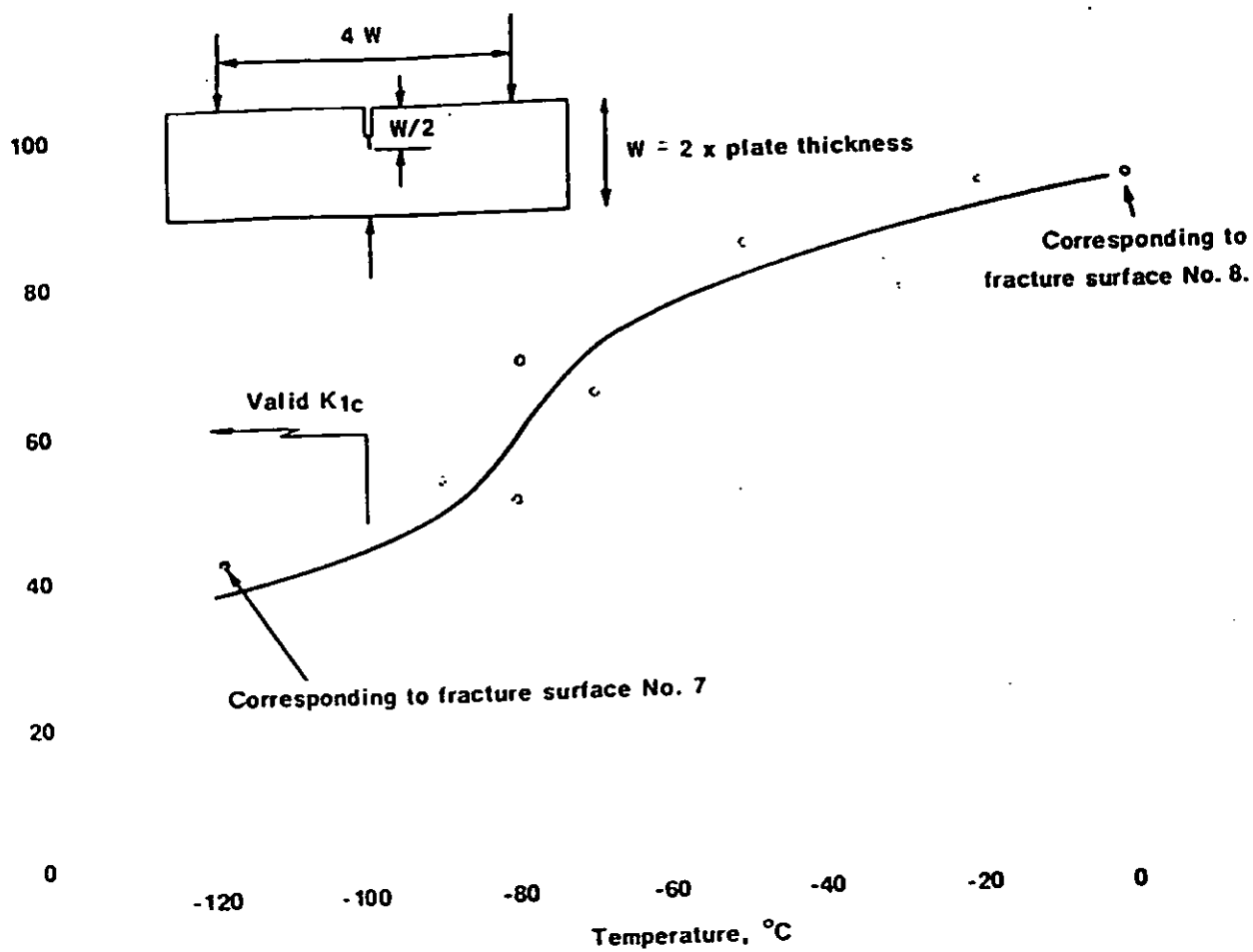


Figure 13 Fracture surfaces of SENB test specimens used to measure fracture toughness in the laboratory.
(7) low temperature test. (8) ambient temperature test



1. 14 Fracture toughness transition curve for a 50 mm thick mild steel.

Fracture Surface Assessment

Mock Test

Time allowed: 1 hour

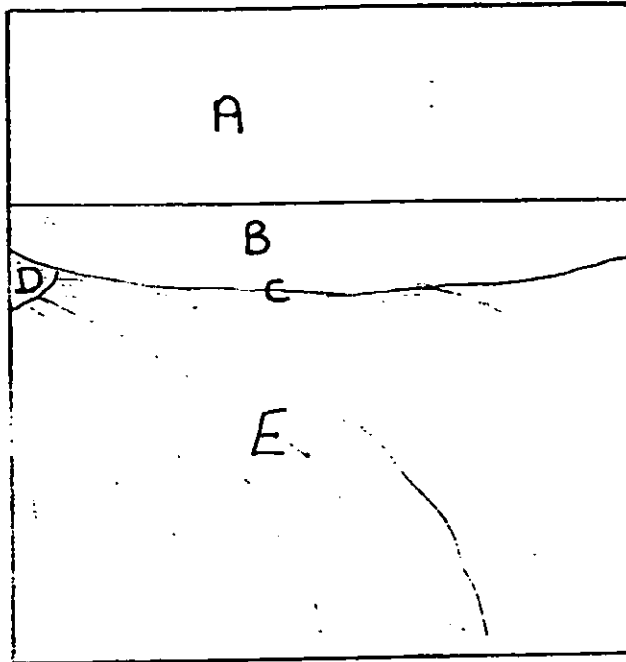
Instructions

1. Sketch the fracture surface.
2. Indicate fracture initiation points.
3. Show any weld defects if present.
4. Identify primary mode of failure.
5. Identify secondary mode of failure.
6. State whether failure occurred in the weld metal, parent metal or both.
7. Write a conclusion to summarise, provide reasons for/evidence to support your findings.
8. Sign and date your report.
9. If in doubt, ask!

Assessment

Presentation	6 marks
Sketch	8 marks
Identification of primary mode	20 marks
Identification of secondary mode	16 marks
Marks possible	50 marks

Fracture Surface Assessment Report Form



- A. Machined Notch.
- B. Fatigue crack,
- C. Beachmark.
- D. Point of Failure.
- E. Brittle failure zone.

1) The fracture initiation point is point A, which is the notch.

2) Point D is a defective inclusion.

3) The primary mode of failure is fatigue.

4) The secondary mode of failure is brittle.

5) Not possible to answer due to lack of information.

6) Primary mode of failure is fatigue due to the smooth surface of the area B and the beachmark at C.

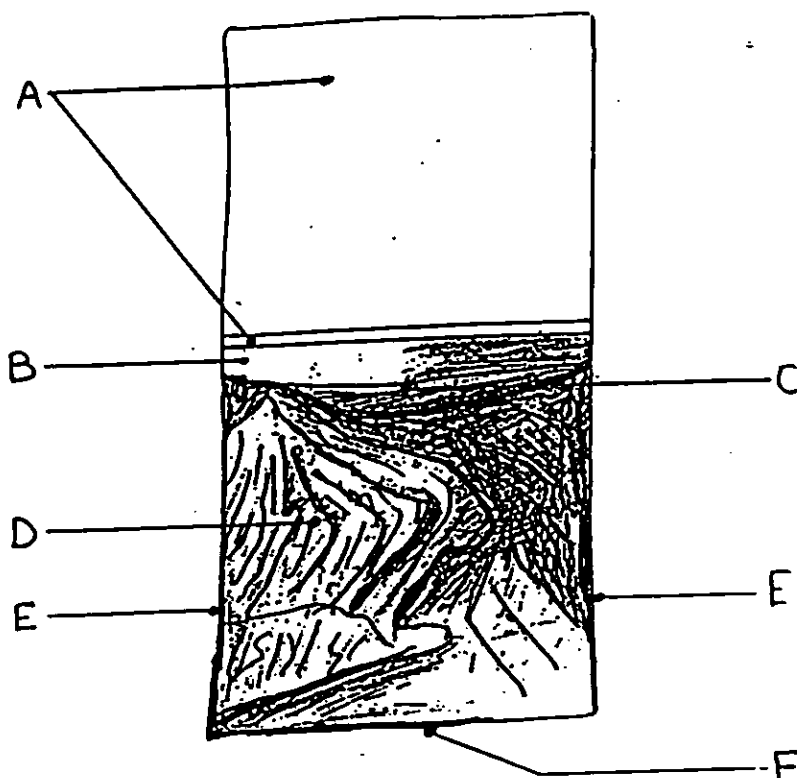
The way that the fracture lines in area E all seem to radiate from D would suggest Brittle fracture, even though the surface is rough.

Name: Gary Forester.

Date: 20.10.98.

Signed: Gary M Forester.

Fracture Surface Assessment Report Form



INDICATIONS:

1. MACHINED NOTCH.
3. SMOOTH FRACTURE SURFACE.
- C. BEACH MARK.

- D. CHEVRON INDICATIONS.
- E. SLIGHT REDUCTION IN AREA + SHEAR LIPS.
- F. FINAL POINT OF FRACTURE.

PRIMARY MODE OF FAILURE: FATIGUE.

SECONDARY MODE OF FAILURE: BRITTLE/DUCTILE (50%-50%).

CONCLUSION:

The fracture from this specimen initiated from an artificially induced defect by machine notching and fatigue cracking the specimen before testing. The primary mode of failure is the fatigue crack this is apparent by the smooth fracture surface and beach mark (B & C). The secondary mode of failure is a brittle/ductile fracture, this is apparent by the chevron indications (D) indicating a brittle fracture. The slight reduction in area + shear lips (E) indicating slight ductility. The chevron point back to the point of initiation.

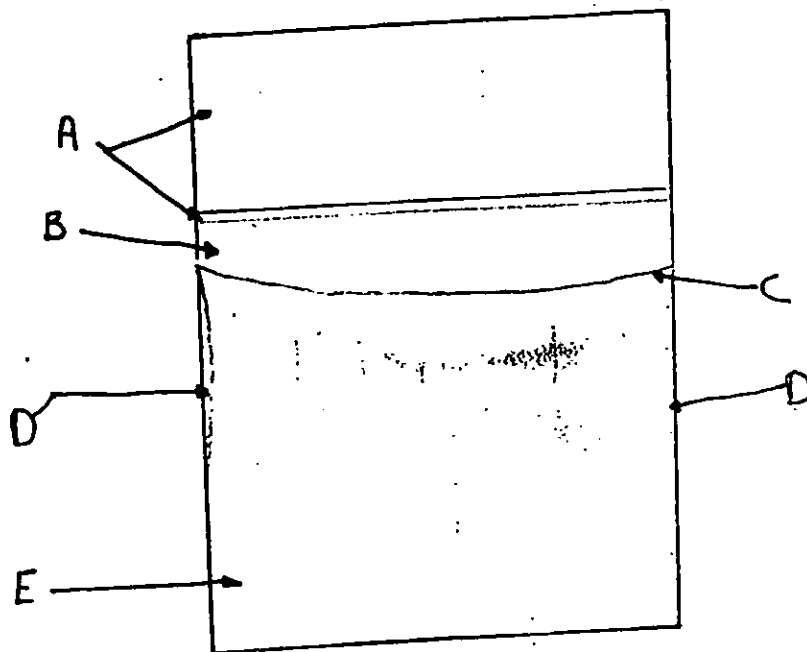
Name: MARK ROGERS

Date: 1-3-96

Signed:

M.R.

Fracture Surface Assessment Report Form



A:- Machined Notch.
B:- Smooth Fatigue surface
C:- Beach Mark.
D:- Slight reduction in area
& shear lips.
E:- Brittle failure.

Primary mode of failure :- Fatigue.

Secondary mode of failure :- Brittle/Ductile (50/50).

The primary mode of failure is from fatigue. This is shown by the smooth failure surface in area B, and also by the beachmark as indicated by C.

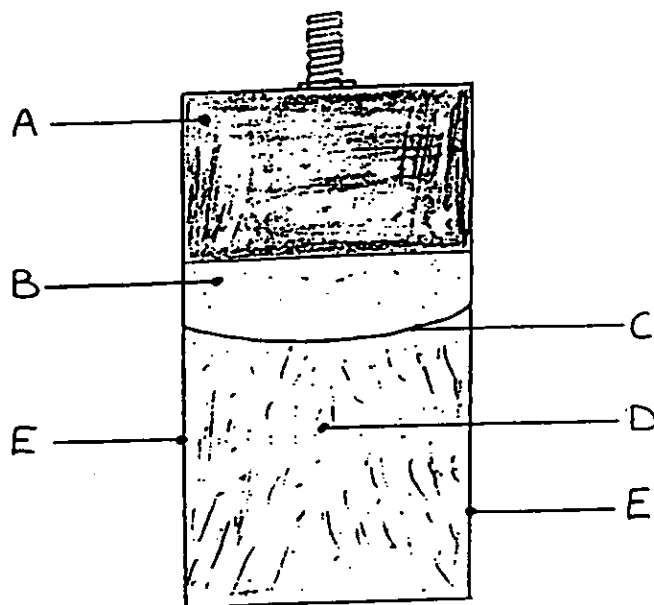
The secondary mode of failure is Brittle/Ductile, and this is indicated by the smooth failure in area E for the brittle failure, and the ductile failure is indicated by the slight reduction in area and shear lips at D.

Name: Gary Forester.

Date: 20.10.98.

Signed: Gary M Forester.

SPECIMEN 3.
IOD TEST



- MACHINED NOTCH
- A SMOOTH FRACTURE SURFACE
- SLIGHT BEACH MARK.

- SLIGHT BEACH MARK.
- D - FLAT, CRYSTALLINE FRACTURE SURFACE - CHE/IRON INDICATED
- FAINT EVIDENCE OF SHEAR LIPS.

PRIMARY MODE OF FAILURE: FATIGUE.

SECONDARY MODE OF FAILURE: BRITTLE FRACTURE.

FAILURE OCCURRED IN THE PARENT MATERIAL.

CONCLUSION.

CONCLUSION.
The fracture in this specimen initiated from an artificially introduced defect, by machine notching (A) & fatigue cracking (B) of the specimen before testing. The purpose of the fatigue crack was to produce a sharp natural crack tip which is important since resistance to fracture is affected by resistance to sharp crack-like defects which decrease P_{TD} .

Name: ERIC DARLEY

Date: 13/12/95

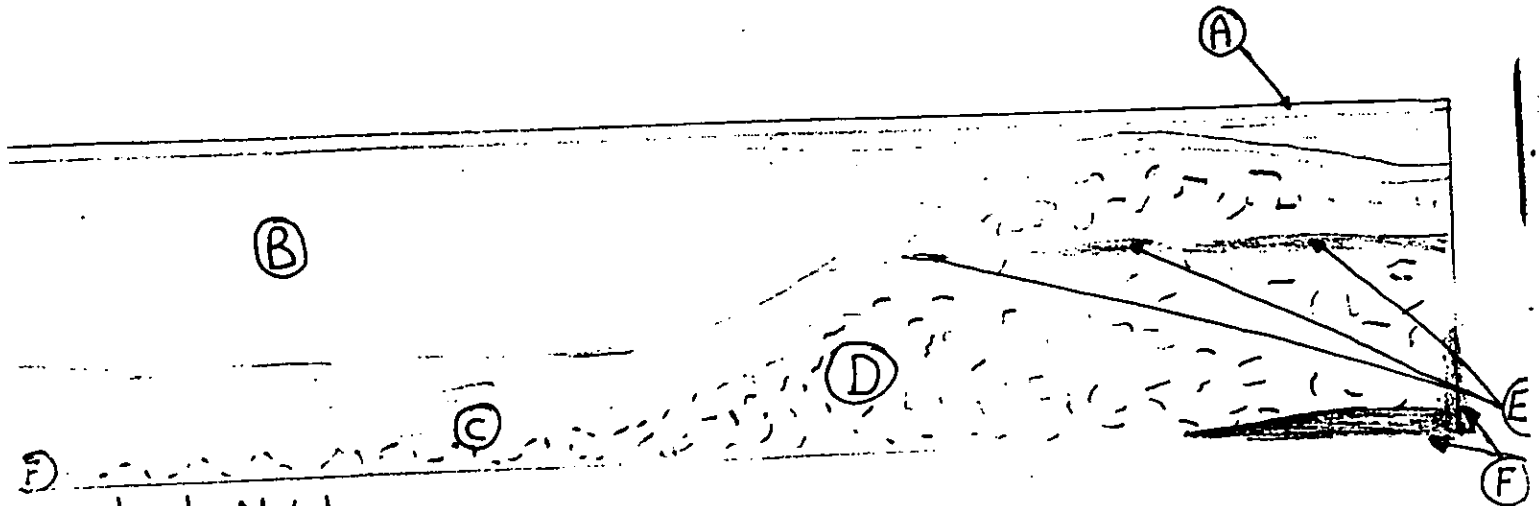
Signed:

Frank D.

1
Distance to fracture. Brittle fractures initiate from
sharp cracks.

A specimen was tested at low temperature and showed
comparatively flat fracture (D), with slight evidence of
beard lip along the edges of the fracture.

Fracture Surface Assessment Report Form



- 1) Machined Notch.
- 2) Smooth fracture surface.
- 3) Beach Mark.
- 4) Random Fracture surface.
- 5) Laminations.
- 6) Shear Lips.

Primary mode of failure :- Fatigue.
Secondary mode of failure :- Ductile.

Conclusions

The primary mode of failure is indicated by the smooth fracture surface at and the beachmark at C.
Secondary mode of failure is indicated by the rough random surface in D and shear lips at F.

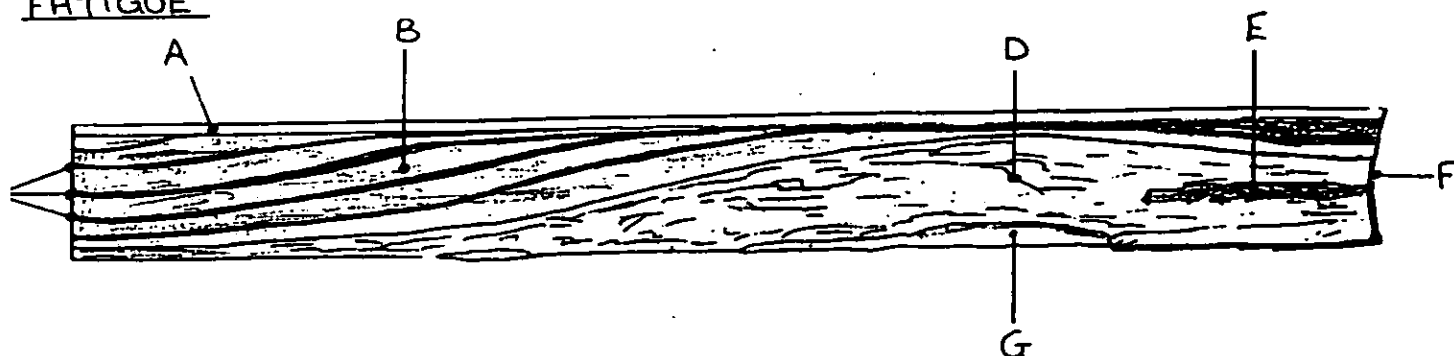
Name: Gary Forester.

Date: 20.10.98.

Signed: Gary M. Forester.

Fracture Surface Assessment Report Form

SPECIMEN 1
FATIGUE



INDICATIONS:

- A - MACHINED NOTCH / SAW CUT
- B - SMOOTH FRACTURE SURFACE.
- C - BEACHMARKS.
- D - DULL GREY FIBROUS SURFACE APPEARANCE.
- E - FAULT LINE.

F - SHEAR LIP.

G - LOCALISED TEARING AT FINAL FAILURE.

PRIMARY MODE OF FAILURE: FATIGUE.

SECONDARY MODE OF FAILURE: DUCTILE FRACTURE.

FAILURE OCCURRED AT THE TOE OF A TEE BUTT WELD. SEE OVER).

CONCLUSION:

1) fatigue crack was artificially induced (A) & the specimen was subjected to various fatigue stress intensities to deliberately induce a smooth fracture surface & beachmarks (B+C). In reality beachmarks are usually closer together & are not so obvious.

Final ductile overload, secondary mode of failure, is evident through a dull grey fibrous surface appearance (D), a reduction in area shear lip (F) and localised tearing at the point of final failure. Fault line (E), probably due to a lamination is also evident.

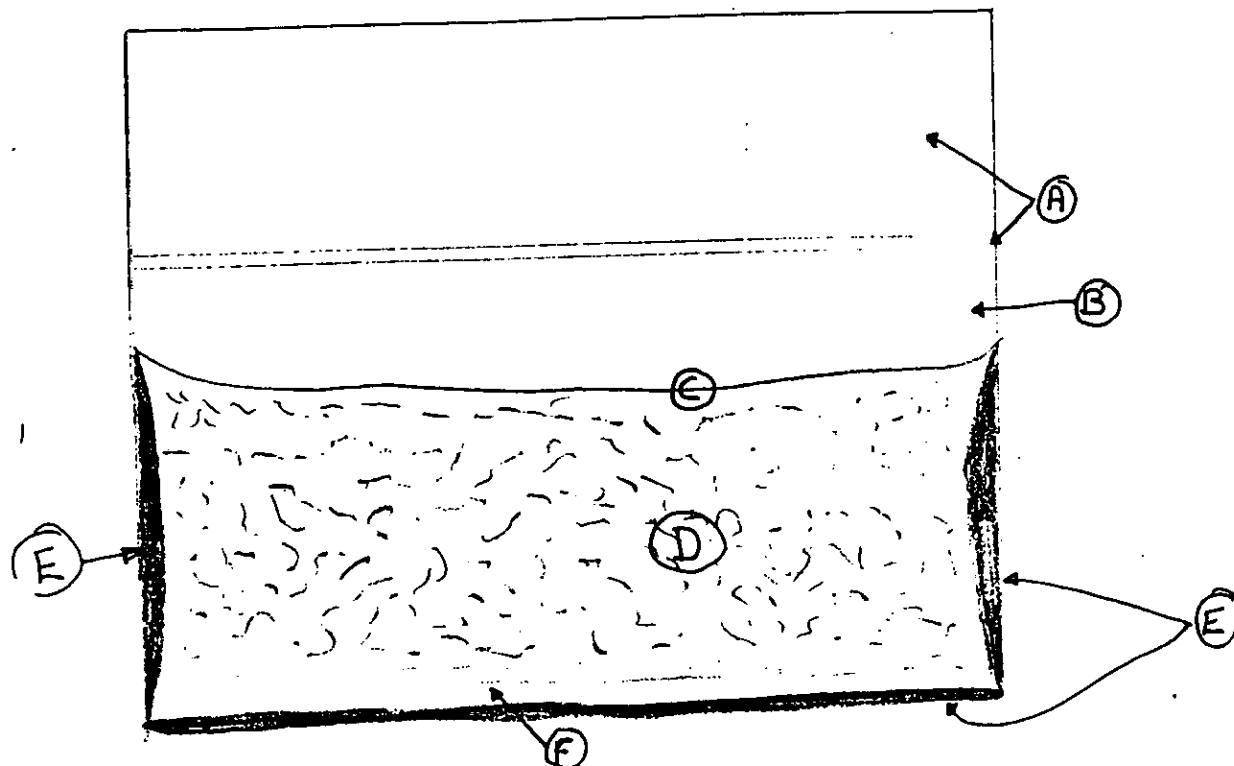
Name: ERIC DARLEY

Date: 11/12/95

Signed:

Eric Darley

Fracture Surface Assessment Report Form



- A) Machined Notch.
- B) Smooth Fatigue Failure area.
- C) Beach Mark.
- D) Rough/random fracture surface.
- E) Shear Lips.
- F) Area of final failure.

Primary Mode of failure :- Fatigue.

Secondary Mode of failure :- Ductile.

P.T.O.

Name: Gary Forester.

Date: 20.10.98.

Signed: Gary M Forester.

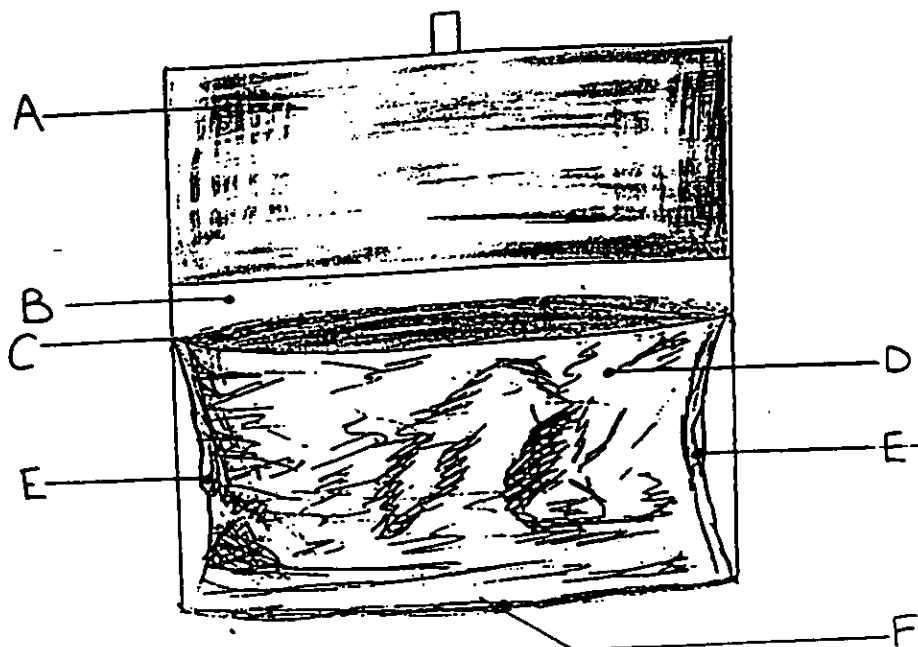
conclusions.

1. primary mode of failure is fatigue, and this is indicated by the smooth fracture surface in area B, and the beachmark at C.

2. secondary mode of failure is ductile and this is indicated by the rough, irregular fracture surface at D and by the reduction in area & shear lips at E.

Fracture Surface Assessment Report Form

Specimen 2.
TOD TEST.



INDICATIONS.

- 1- MACHINED NOTCH.
- 2- SMOOTH FRACTURE SURFACE.
- BEACHMARK
- 3- DULL GREY FIBROUS SURFACE APPEARANCE
- 4- SHEAR LIPS.
- SHEAR FRACTURE.

PRIMARY MODE OF FAILURE: FATIGUE.

SECONDARY MODE OF FAILURE: DUCTILE FRACTURE.

FAILURE OCCURRED IN PARENT METAL.

CONCLUSION:

The fracture in this specimen initiated from an artificially induced defect, made by machine notching and fatigue cracking the specimen before testing. The extent of the fatigue crack is shown by the very smooth surface (A) & the beachmark (C) below the machined notch (A)

P.T.O.

Name: ERIC DARLEY

Date: 12/12/95

Signed:

Eric Darley

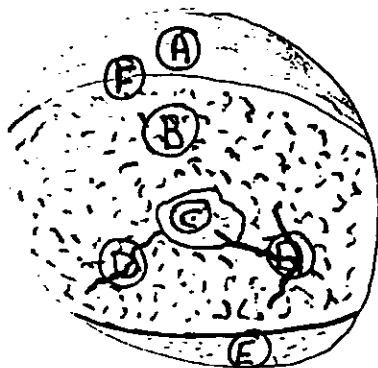
Welding Inspection Practical (CSWIP)

1. The purpose of the fatigue crack was to produce a sharp natural crack tip.

The secondary mode of failure indicates that the specimen was tested at room temp. The main points being a flat central region of a grey fibrous appearance (D) with a reduction in area, shear lips (E) at the sides of the specimen.

A large region of shear fracture (F) has developed at the base of the specimen caused by the three point bending rig. Compressive bending stresses were induced by the applied bending stress and reaction stress from the anvil. produced this feature of shear fracture.

Fracture Surface Assessment Report Form



- A) Fatigue Area .
- B) Rough Random Fracture surface .
- C) Area of Inclusion .
- D) Crack-like indications .
- E) Shiny fatigue surface .
- F) Beach Mark .

Primary mode of failure :- Fatigue .

Secondary mode of failure :- Ductile / Brittle

Conclusions .

The primary mode of failure is fatigue failure as indicated by the smooth surface at Area A and the beachmark F. This initiated from the bottom of the thread .

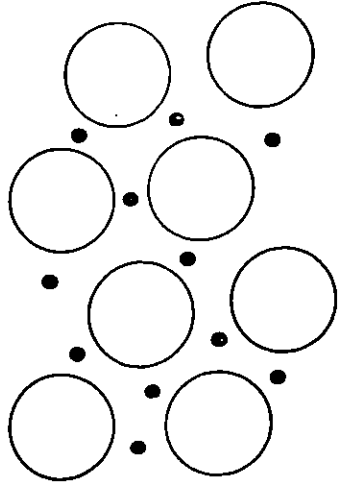
The secondary mode of failure is ductile ^{brittle} failure and is indicated by the rough and random failure of area B, and the brittle area of failure is indicated on the smooth shiny surface of area E .

Name: Gary Forester .

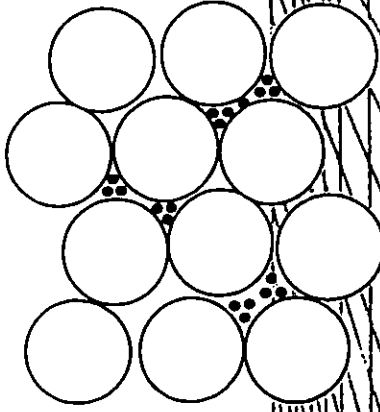
Date: 12/12/95 .

Signed: Gary Forester .

The effect of hydrogen in steel (2)



- Steel in the expanded condition during welding.
- H₂ enters the weld via the arc during welding. Hydrogen will break up into its atomic state above ~200°C.



- At a temperature below ~200°C the steel contracts leaving small gaps between the iron atoms. The hydrogen atoms collect in these gaps and revert to a molecular state (as hydrogen gas).
- When the hydrogen collects in large amounts great pressure may be exerted.

*Ruane &
T P O'Neill*

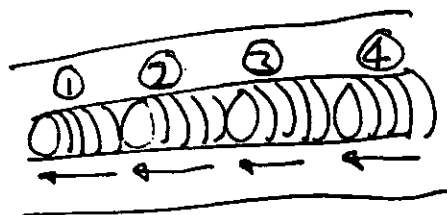
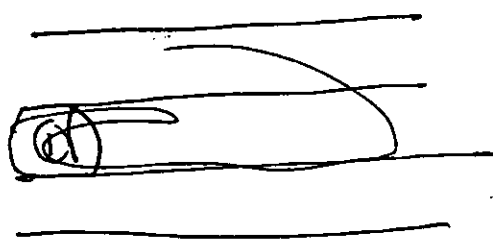
Material Properties which affect distortion:

Coefficient of Thermal Expansion

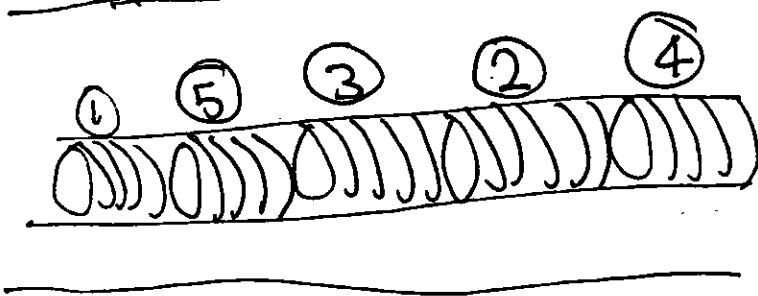
This is the measure of the amount of expansion a material undergoes when it is heated, or contracted when it is cooled. Materials of high t.e. expand more which allow more distortion.

ib A-2.

Back Stop



Back skip



Methods of Reducing Distortion

Using Intermittent Welds

Use as few welds as possible

Place welds near neutral axis.

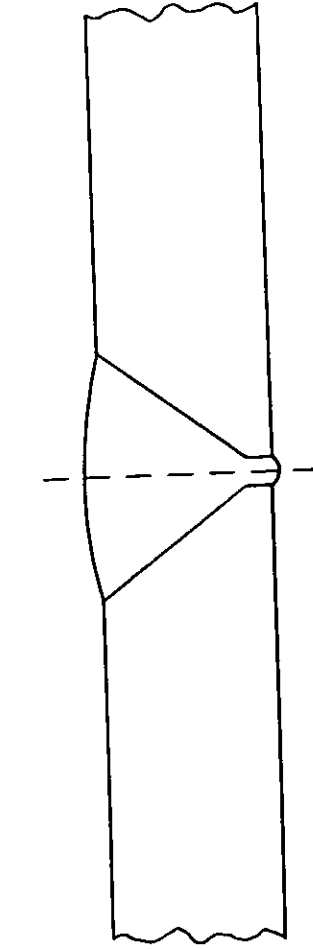
Use a different joint design.

Use a balanced welding Technique

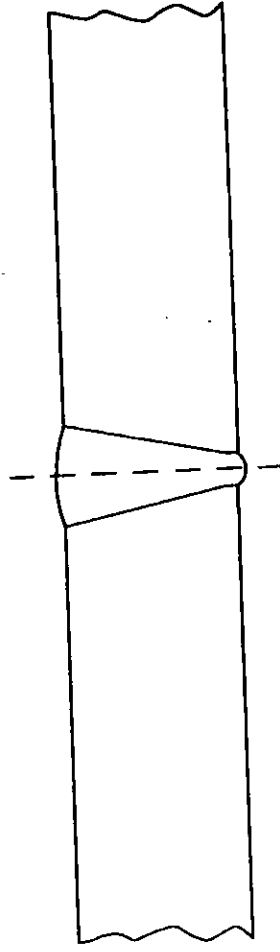
1
increase welding time by using a faster welding process.
reduced restraint.
less heating.
resetting.

Depth to width ratio for single pass butt welds

For single pass welds it is generally better to have a depth to width ratio less than 1.4 : 1 or $\frac{W}{D} < 0.7$.



Cracking unlikely; depth to width ratio less than 1.4 : 1.



If the ratio exceeds 1.4 : 1, the weld is more prone to cracking.

Welding plant

- Transformer:
 - Changes mains supply voltage to a voltage suitable for welding. Has no moving parts and is termed *static plant*.
- Rectifier:
 - Changes a.c. from the transformer into d.c.. Can be mechanically or statically achieved.
- Generator:
 - Produces welding current. The generator consists of an armature rotating in a magnetic field, the armature must be rotated at a constant speed either by a motor unit or, in the absence of electrical power, by an internal combustion engine.

■ Inverter

~~An inverter changes d.c. to a.c. (opposite to a rectifier)~~

**Buane & I
TPO'Neill**

Inductance or choke

- Applicable to MIG/MAG welding in the dip transfer mode.
- The electrode is fed slowly through the arc until it touches the weld pool, at this point the output from the power supply is short circuited and a very high current flows through the electrode. If this was allowed to continue, the wire would melt and eject excessive spatter.
- The inclusion of the inductance in the welding circuit controls the **rate** at which the current rises to that the electrode tip is melted uniformly and flows into the molten pool without excessive spatter.

- The cycle is repeated 50 to 200 times each second

Ruane & H
T.P. O'Neill

Synergic MIG/MAG welding

- Synergic MIG/MAG welding establishes a relationship between the following:

- voltage;
- current;
- waveform;
- pulse;
- frequency;
- wire feed rate.

- Automatic correction can be made during welding.

- Apart from ensuring greater consistency in weld quality, synergic MIG/MAG welding plant offers single dial control

which is easier for the welder to set up.

- Synergic MIG/MAG welding plant can operate in the dip, spray and pulsed transfer modes.

**Buane &
T.P. O'Neill**

Welding Circuit Voltage

- **OCV (Open circuit voltage)** - the voltage available between the output terminals of a welding plant ready for welding but carrying no current.
- **Arc voltage** - the voltage produced between the electrode and the work, measured as close as practicable to the arc.

Note: Arc voltage is a function of arc length, e.g.

~~increasing the length of the arc increases the voltage and vice versa, therefore arc length is a function of voltage~~

Inverter power units

- Inverter power units are relatively light and small.
- Method of operation:
 - A three phase 50Hz a.c. mains power supply is first rectified to give d.c..
 - This d.c. current is fed to the inverter which converts it back to a.c. at a higher frequency (5-25kHz).
 - The a.c. produced is then passed through a lightweight transformer to step down the voltage into welding voltage.
 - Finally, if required, this a.c. current is rectified to produce d.c..

■ In arc welding plant the greatest weight is that of the transformer because of the laminated steel core, but as a.c. frequency increases the core size decreases, hence the lower weight.

Buane & I
IRONAIL

Mechanical properties

- **Brittle** - The tendency of a material to fail suddenly by breaking without any permanent deformation of the material before failure.
- **Ductility** - The ability of a material to be drawn into wire.
- **Elasticity** - A materials ability to return back to its original size.
- **Hardness** - The ability of a material to resist indentation, abrasion or scratching.
- **Malleability** - The ability of a material to bend or deform without breaking.
- **Plasticity** - Permanent deformation of a material due to the slip of crystal planes once the tensile load is removed.
- **Toughness** - The ability of a material to withstand cracking.

Buane & /
T.P.O'Neill

Material Properties Which Affect Distortion

■ Coefficient Of Thermal Expansion:

This is the measure of the amount of expansion a material undergoes when it is heated, or contracted when it is cooled. Materials of high thermal expansions expand more which allows for more distortion.

■ Thermal Conductivity:

Is a measure of the ease at which heat will flow through a material. Materials of low thermal conductivity are more prone to higher shrinkage/distortion when compared to materials of higher thermal Conductivity.

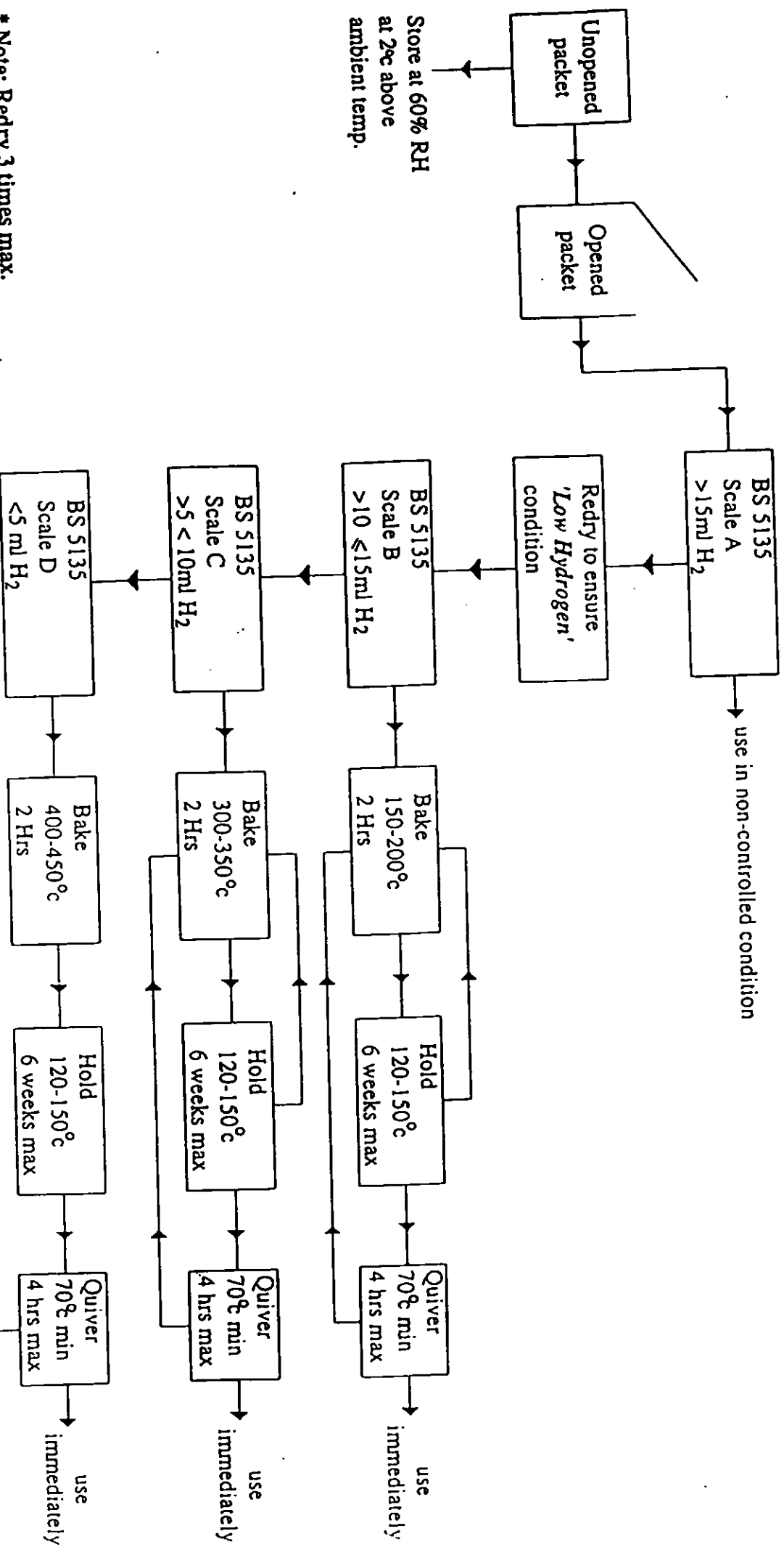
■ Yield Strength:

On cooling stresses reach the yield point of material; Higher yield points cause higher residual stresses that can act to increase distortion. When possible materials are best welded in their annealed (low strength) conditions.

■ Modulus Of Elasticity:

Is the a measure of a materials stiffness. High modulus resists distortion.

Typical redrying procedure for Basic coated electrodes (see specific manufacturers instructions)



Basic coated electrode

- For basic coated electrodes to be classified as *hydrogen controlled*, they must be able to produce welds with a hydrogen content below 15 ml of hydrogen per 100 g of weld metal deposited as to BS 639.

The above statement depends on many factors:

- The electrodes must be baked as to manufacturer's recommendations. This is to drive off any moisture in the electrodes' flux. Vacuum packs are available and do not require pre-baking.
- The electrodes must be used with a minimum arc length. Hydrogen enters the weld via the arc.

- The electrodes must be used with a minimum weave. As the welder weaves the electrode, the arc gap is increased.
- The parent material to be welded must be free from moisture and contamination.

Arc Energy; Heat Input

- Arc energy and heat input may not be the same.
- From amps, volts and travel speed we measure arc energy (energy input).
- BS 5135 refers to arc energy for MMA which should be divided by given factors to estimate conditions for the other processes.

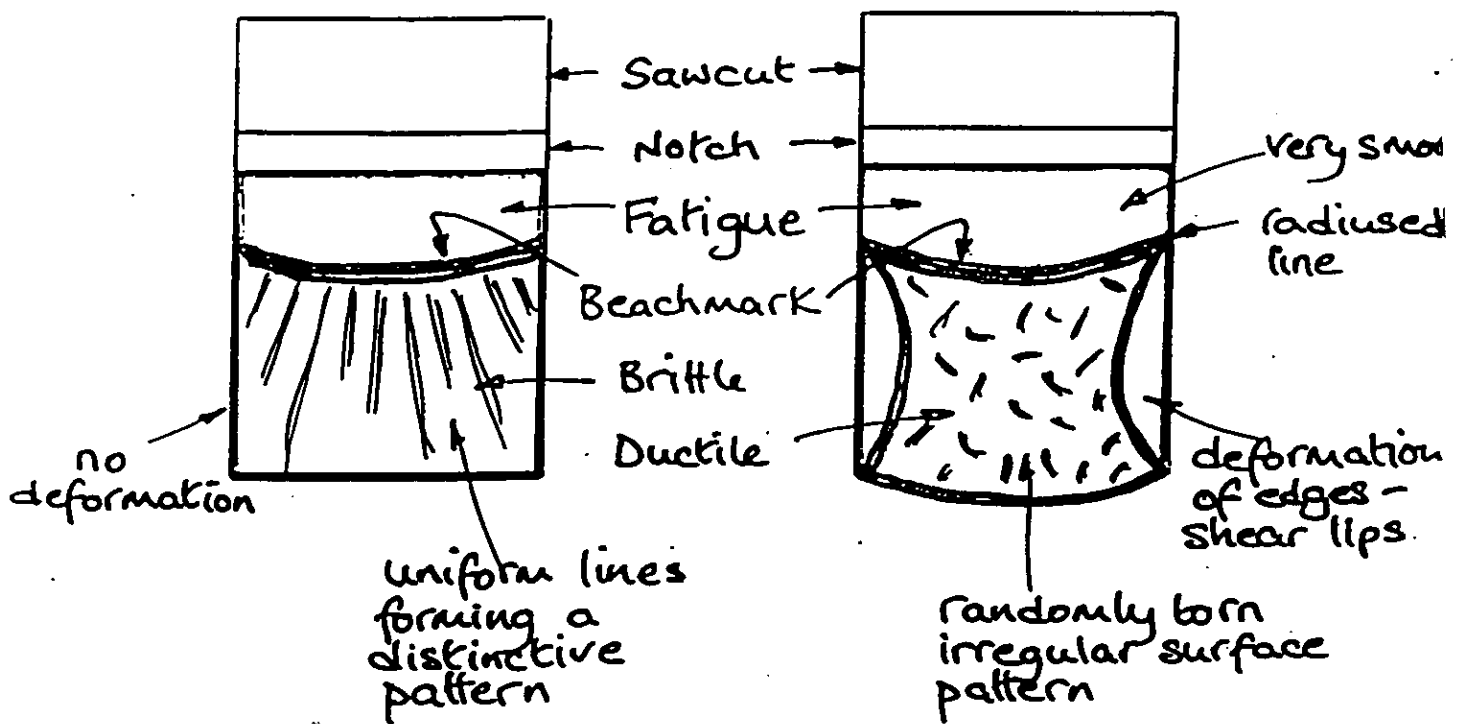
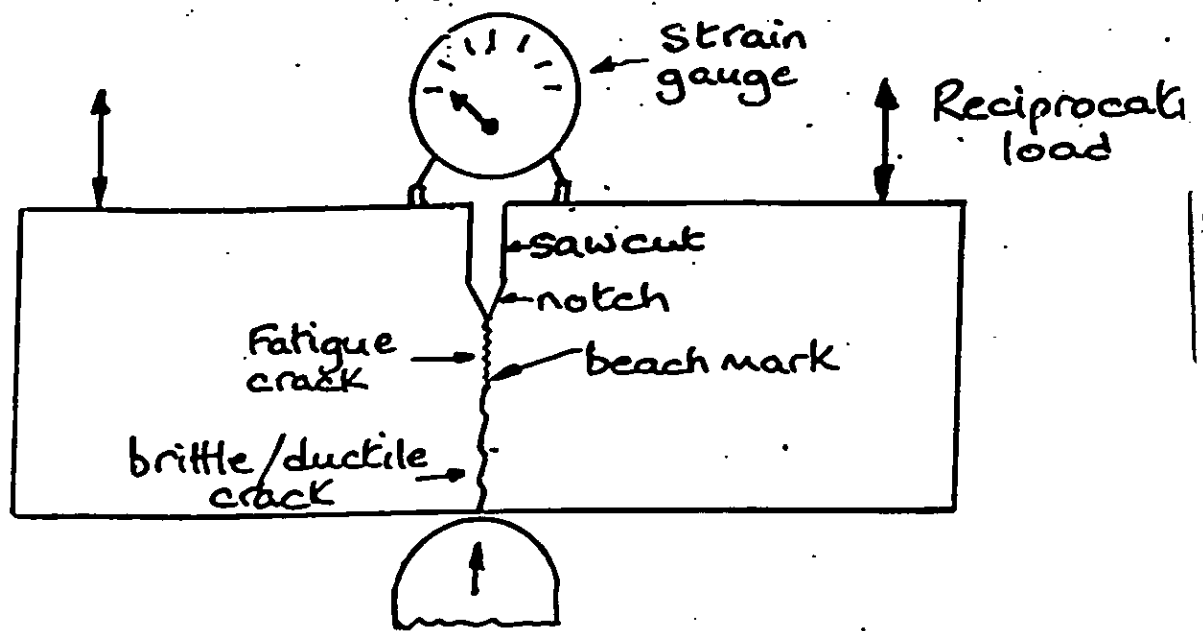
MMA	= 1.0
SA	= 0.8
MIG	= 1.0
TIG	= 1.2

- In preN 1011 it is assumed that HI equals AE for submerged arc welding and multiplying factors are applied for other

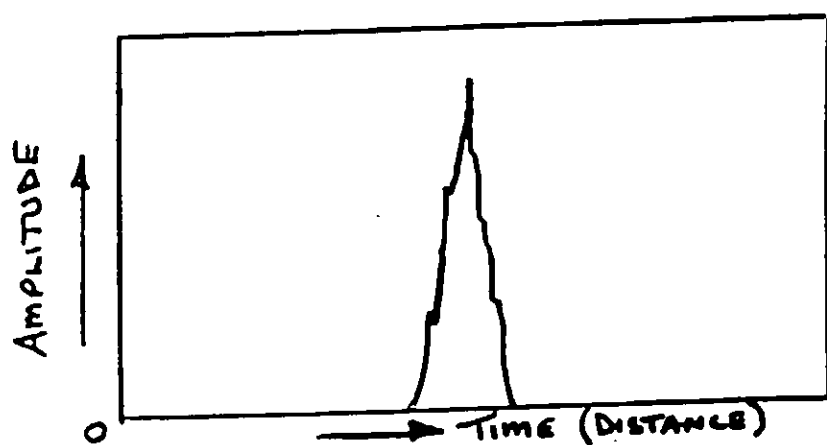
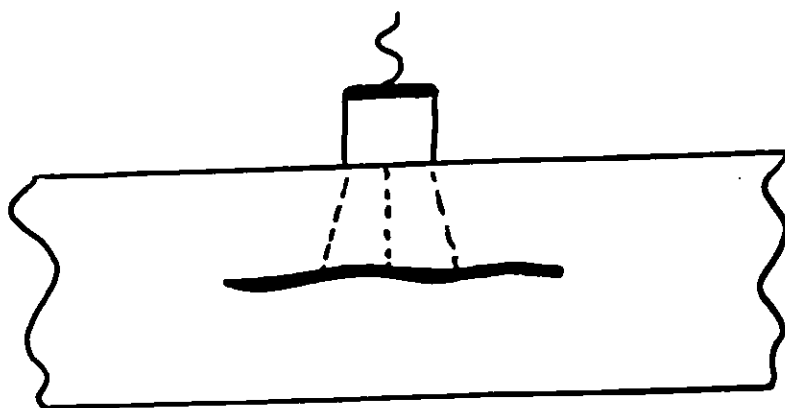
Processes

SA	= 1.0
MMA, MIG, FCAW	= 0.8
TIG, PAW	= 0.6

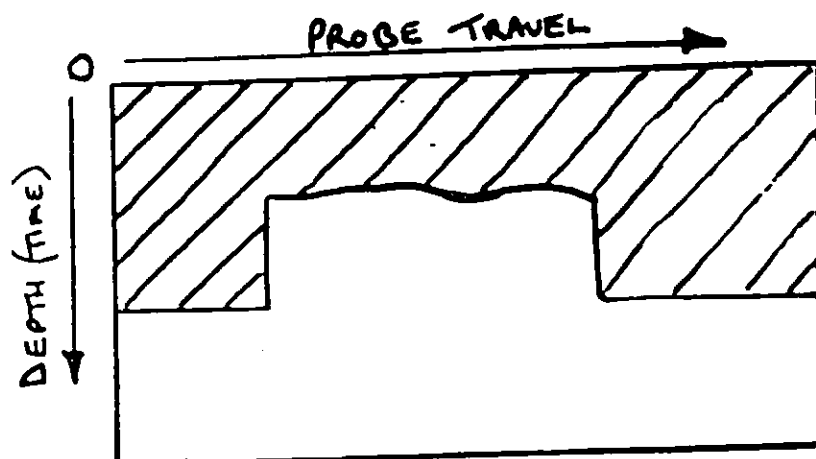
C. T. C. D test.



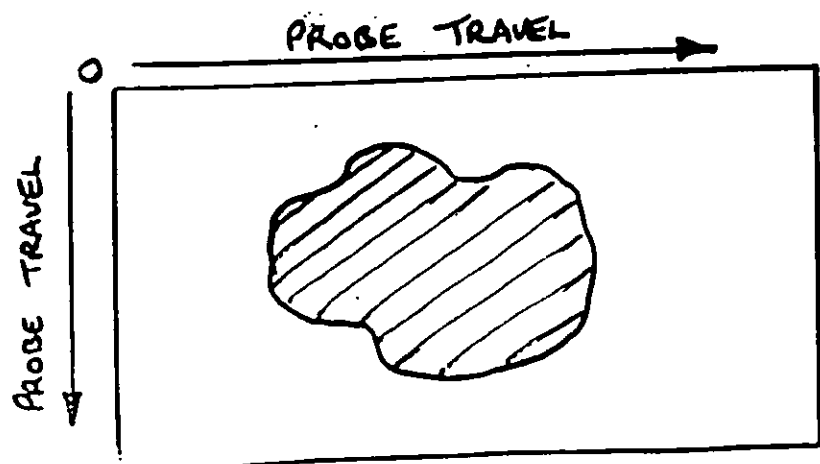
METHODS OF DATA PRESENTATION:



A SCAN



B SCAN



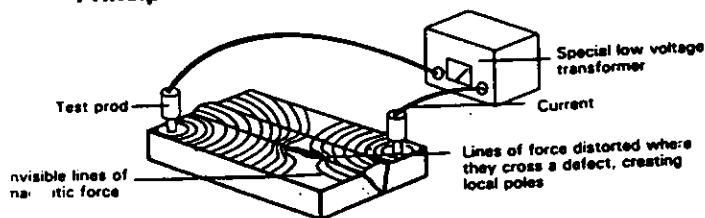
C SCAN

Non Destructive testing is a method of carrying out an inspection, on a component or fabrication. The item under inspection remains structurally sound. The defects are indicated by one of the following methods:-

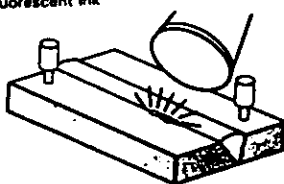
1. MAGNETIC PARTICLE OR DYE PENETRANT

This is normally the lowest cost for basic equipment. The limitations are mainly that the specimen has to be magnetised and indicates surface defects only. Dye penetrants can be used on most materials and is widely used throughout industry.

Magnetic Particle Principle

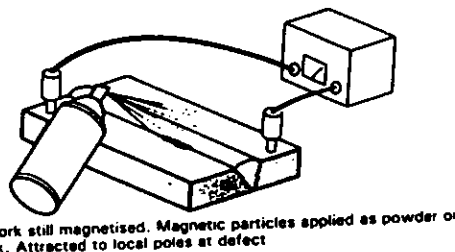


2. Examine in normal lighting (the work may be lacquered white before magnetisation to increase contrast) or examine in ultra-violet light using fluorescent ink

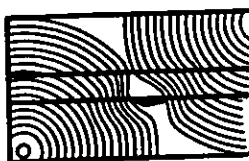


Magnetic Particle Testing

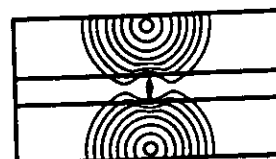
1. Apply particles



3. Repeat as necessary to reveal cracks



Current flow along weld:
Defect running across weld not revealed



Current flow across weld:
Defect running along weld not revealed

Notes

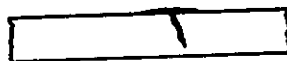
Only ferromagnetic work (ferritic steels and some nickel alloys) can be tested.

The method is sensitive to cracks just under the surface, to the extent that work may be prepared by careful grinding, without the resulting smearing of metal over fine cracks preventing their detection.

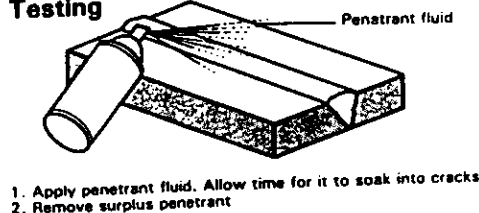
Though more complex in operation than penetrants, requiring special equipment, it offers greater sensitivity and more rapid inspection.

Penetrant Principle

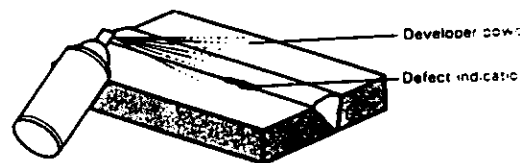
A penetrating fluid is applied to the surface of the piece to be tested and is drawn into any defect. Its presence is revealed as shown.



Penetrant Testing

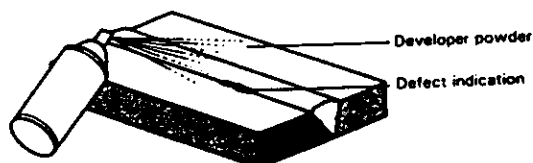


1. Apply penetrant fluid. Allow time for it to soak into cracks
2. Remove surplus penetrant



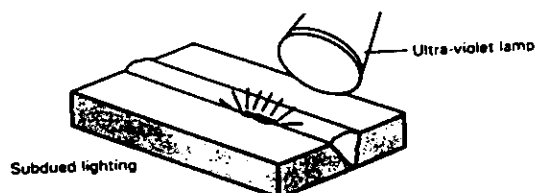
Then either 3A or 3B

- 3A. Apply a chalky developer powder which soaks up the dye penetrant from any defect by reverse capillary action. A surface stain indicates any defect.



Then either 3A or 3B

- 3A. Apply a chalky developer powder which soaks up the dye penetrant from any defect by reverse capillary action. A surface stain indicates any defect



- 3B. View in ultra-violet light which causes the fluorescent penetrant to glow

Notes

The defect is directly indicated by the dye stain or fluorescent glow. The method is sensitive to surface scratches or irregularities, which may give confusing indications. If the surface is ground smooth, metal may be smeared over fine cracks and they will not show up.

With modern aerosols testing is comparatively simple. For large throughputs, tanks may be used for dye application.

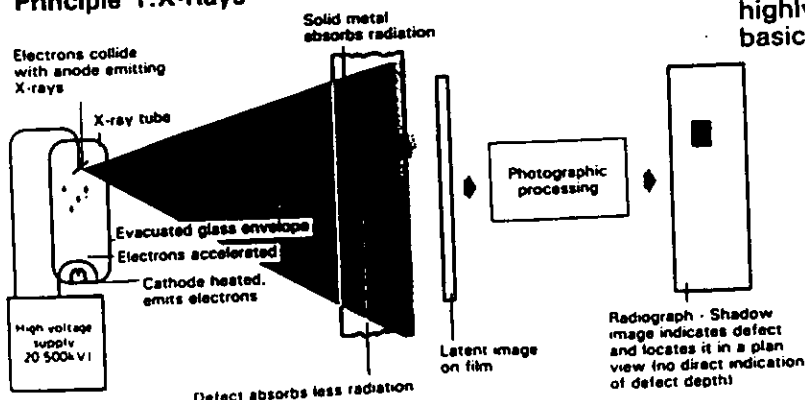
Defects cannot readily be rewelded, as they are contaminated by the trapped penetrant.

This technique is widely applied as a supplement to visual inspection and as a preliminary check before radiography.

SAFETY: Some materials may contain inflammable or toxic solvents. Observe any ventilation recommendations.

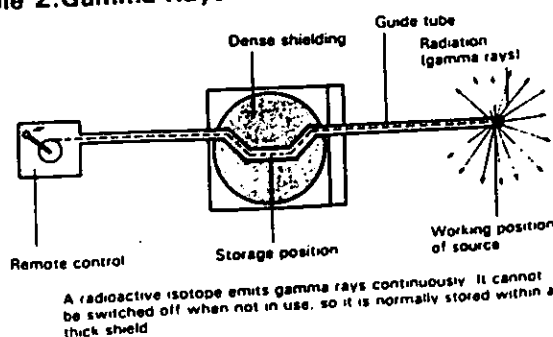
2. RADIOGRAPHY (X-RAYS)

Principle 1: X-Rays



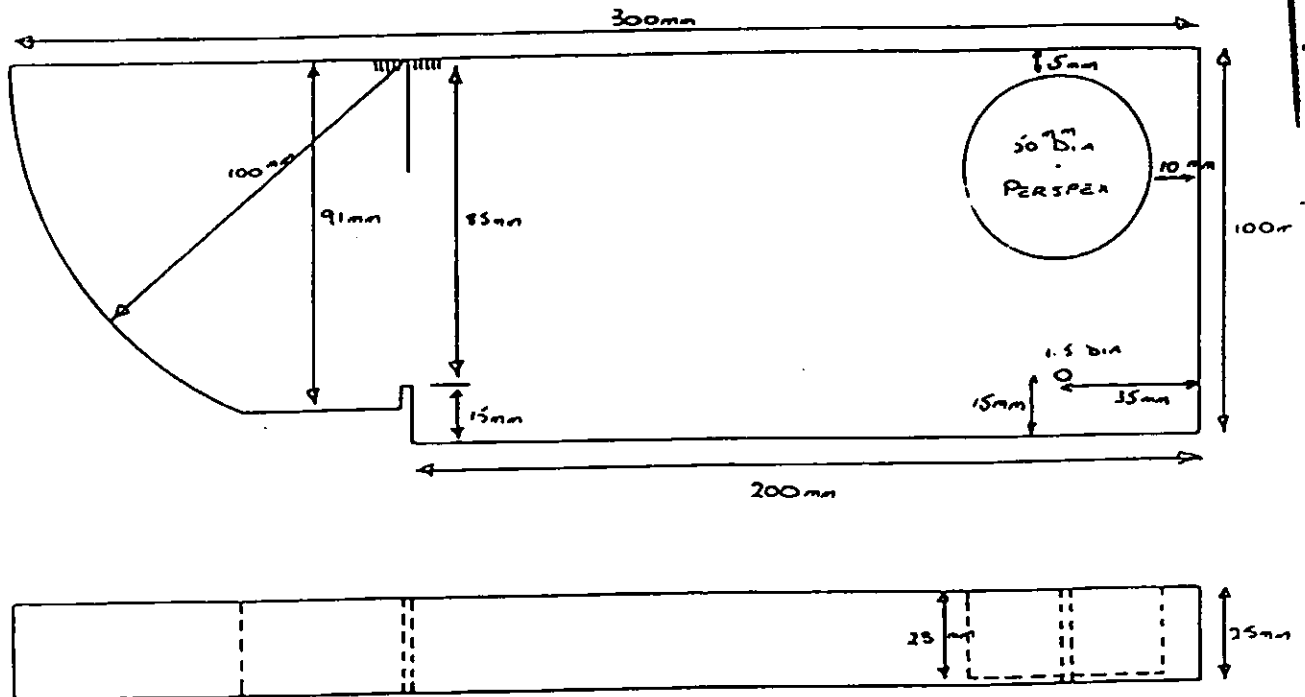
Radiation in the form of X or Gamma Rays are passed through the specimen and a permanent record is kept on Radiographic Film (X-Ray Plate). This method is highly specialised and requires personnel with good basic training in the particular technique.

Principle 2: Gamma Rays



CALIBRATION BLOCKS AND THEIR USES

1) The I.I.W. (International Institute of Welding) Block V1 or A2 Block



ALL DIMENSIONS IN MM

TOLERANCE ± 0.1 MM

USES

a) Compressional Probes

i) Calibration

Thicknesses available - 5, 10, 25, 100, 200 mm. The perspex insert has a thickness of 23mm which is equivalent to 50mm of steel. This serves as a rough calibration check.

TWO OR MORE ECHOES ARE REQUIRED FOR CALIBRATION

Since 91mm compressional = 50mm shear, it is possible to calibrate the time base for shear velocity using a compressional probe.

iii. Probe Angle

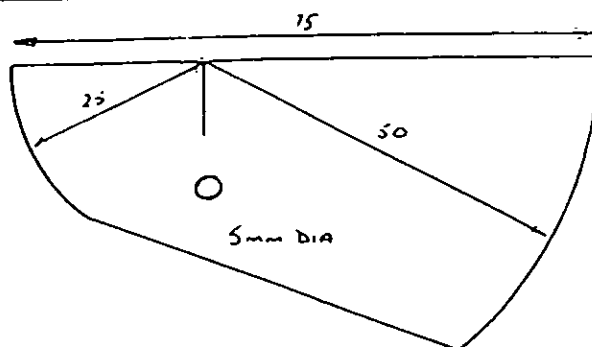
- (a) Approximate - maximise on the 50mm diameter hole and measure the angle on the engraved scale
- (b) Accurate - maximise on the 1.5mm hole, mark the index position onto the block, draw a line from the index point to the centre of the hole and measure the refracted angle with a protractor

Probe angle determination is best done on the 10% beam profile block which offers holes at various depths, the average of at least 3 holes being recommended.

iv. Probe Output

Set the response from the 100mm radius to full screen height and note the number of dB's in gain.

2) V2/A4 Calibration Block



ALL DIMENSIONS IN MM
HOLE SIZE MAY BE 1.5mm
COMMONLY USED ON SITE

a) Compressional Probes

i) Calibration

In accordance with BS 2704, this block can be purchased having a thickness of either 12½ mm or 20 mm.

b) Shear Probes

i) Calibration

When aiming at 25mm radius, signals occur at 25, 100, 175, 250, etc.

When aiming at 50mm radius, signals occur at 50, 125, 200, 275, etc.

ULTRASONIC TEST REPORT PROCEDURE

ULTRASONIC INSPECTION REPORT

IDENTITY TP 27
DATE 5.10.83
INSPECTOR J Smith
MATERIAL Mild steel
DIMENSIONS 32 mm x 240 mm
WELDING PROCESS M.M.A.
EDGE PREPARATION Single 'V' 60° included angle. 2mm root face and gap.
WELD SURFACE CONDITION Unground
PLATE SURFACE CONDITION As rolled

PLATE THICKNESS 32 mm

EQUIPMENT USK6

<u>PROBES</u>	<u>Angle</u>	<u>Frequency</u>	<u>Size</u>	<u>Type</u>
1	0°	5 MHz	10mm	Twin
2	45°	4 MHz	10mm	Single
3	60°	4 MHz	10mm	Single
4	70°	4 MHz	10mm	Single

SENSITIVITIES

Compressional. 2nd BWE to FSH from parent plate.
Angles response from 1.5mm hole at test depth to FSH.

REPORT

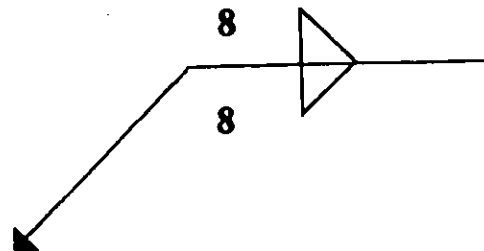
Parent plate compressional scan - Plate A clean. Plate B - isolated inclusions (small) throughout. Not affecting Shear

Weld - Defects as shown.

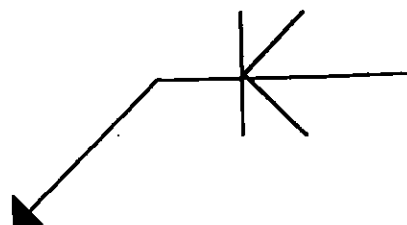
Transverse scan - No transverse defects.

ANSWERS FOR EXERCISE S.W.I. No 1

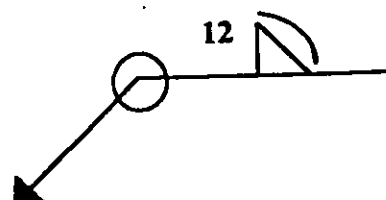
WELD No 1



WELD No 2



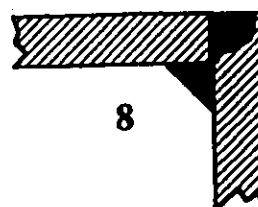
WELD No 3



WELD No 4

ARROW SIDE: 8mm leg length fillet weld,
welded all way round

OTHER SIDE: Single "J" butt weld, 8mm
depth of penetration, 2mm root face, weld
all way round



ANSWERS FOR EXERCISE S.W.I. No1

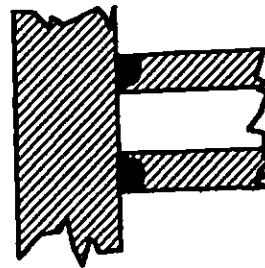
D No 5

e V" butt weld.
ect set up.



D No 6

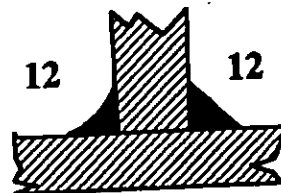
O V SIDE: 8mm single "J" butt weld,
eg all way round, welded on site.



LD No 7

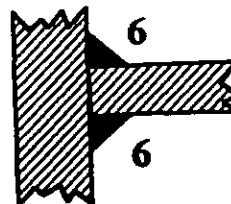
W SIDE: 12mm leg length fillet weld,
throat thickness concaved.

FR SIDE: 12mm leg length fillet weld,
throat thickness.



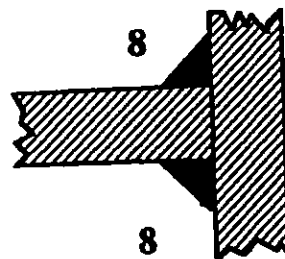
ELD No 8

m leg length fillet weld welded both sides.



ELD No 9

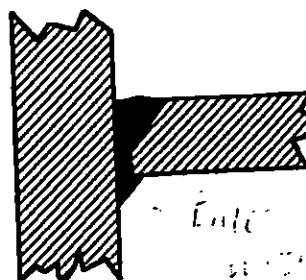
u. leg length fillet weld welded both side,



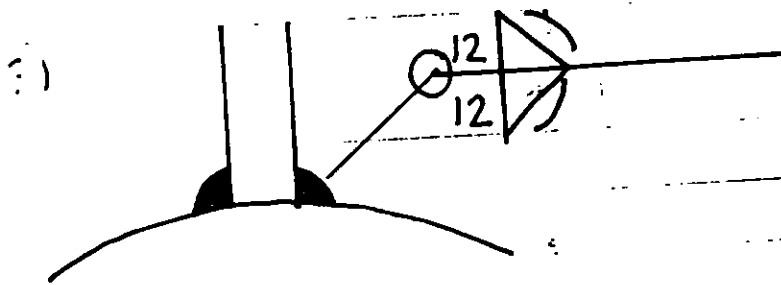
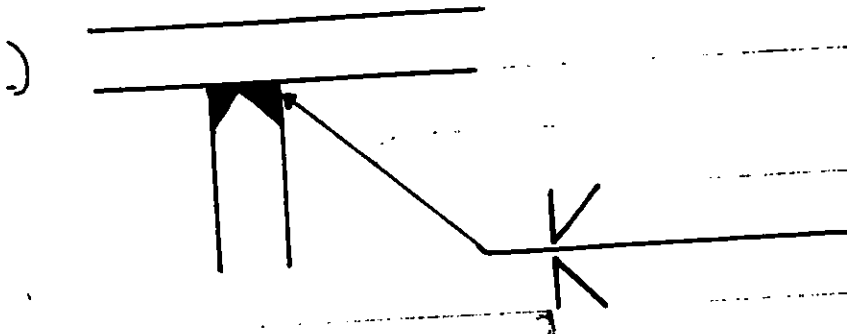
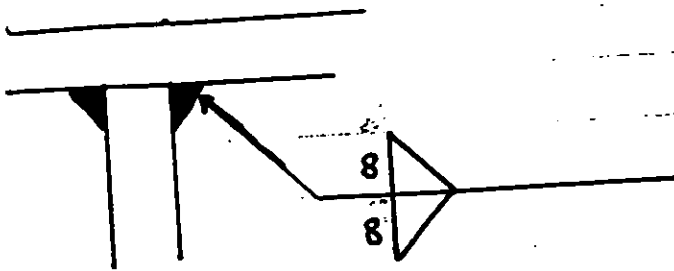
FLD No 10

R LOW SIDE: Single bevel butt weld, depth
penetration 10mm, root face 2mm.

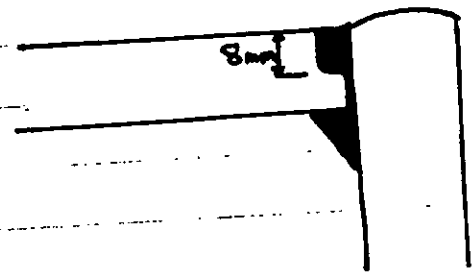
1 HER SIDE: 6mm leg length fillet weld.



SWI : Exercise 1.

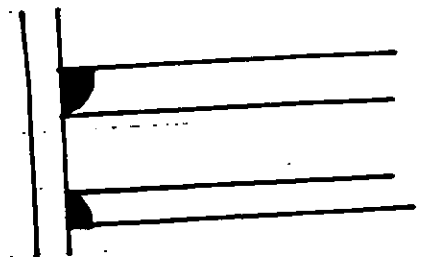


Other side :- Single 'J' prep 8mm deep all way around.
 Arrow side :- Fillet weld 8mm Leg length all way round.

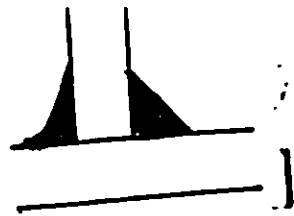


5) Double Vee Prep. both sides.

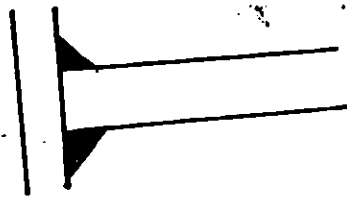
1). Arrow side :- Single 'U' prep all way round
 & welded on site.



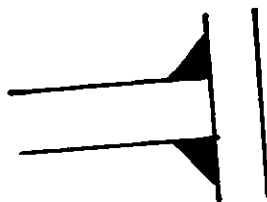
Arrow side :- Fillet weld 12mm leg length, 8mm throat, concave.
 Other side :- " " " " " 10mm "



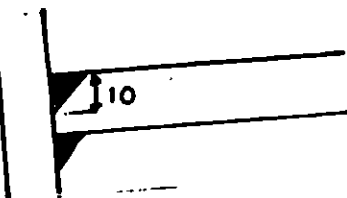
Arrow side :- Fillet weld 6mm leg length.
 Other side :- " " " " "



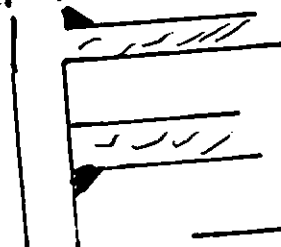
Arrow side } Fillet weld 8mm leg length
 Other side }



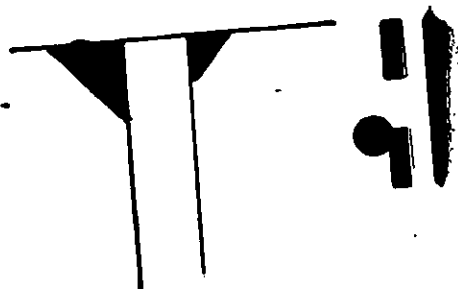
Arrow side :- Single V, 10mm deep.
 Other side :- Fillet weld, 6mm deep.



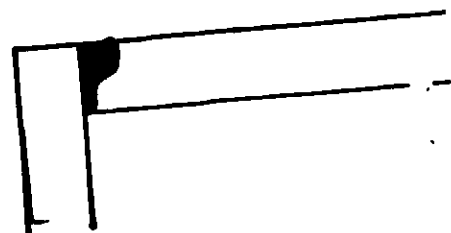
8mm leg length fillet weld all way round.



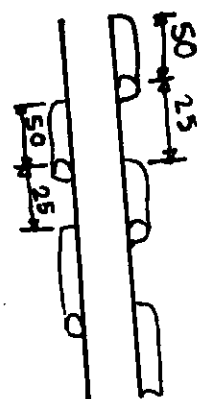
Arrow Side :- Fillet weld 20mm leg length, 14mm throat.
 Other Side :- " " 10mm " " 7mm "



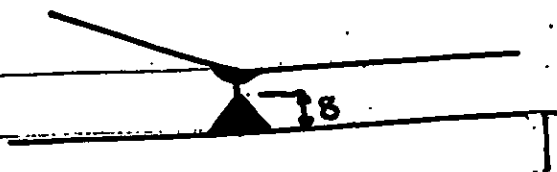
1) Single 'J' Prep on arrow side welded with MAG.



Arrow side :- Fillet welds intermittent 50mm lg with 25mm gap & 6mm leg length.
 Other side :- Fillet weld intermittent 50mm lg with 25mm gap & 6mm leg length, staggered



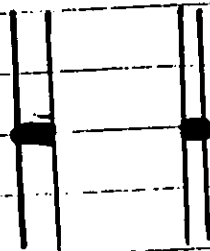
or side :- Sealing run ground flush.
 or side :- Single Vee, 8mm deep.



Single J' prep on arrow side, ground flush.



Arrow Side :- Square butt with a convex cap, welded all way round on-site.



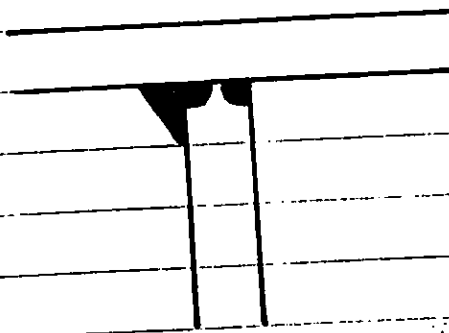
Single 'U' on arrow side



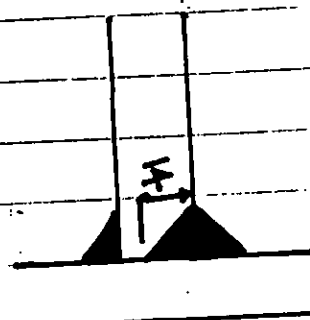
Arrow Side :- Sealing run.
 Other side :- Single 'V' ground flush.



Single J on both sides X
 Single J prep with 8mm fillet
 imposed on arrow side.



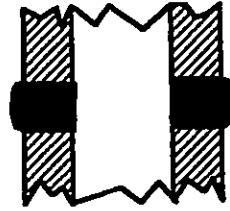
Arrow side :- Fillet weld, 4mm leg length.
 Other side :- Single Bevel Butt 14mm deep,
 with Fillet weld, 6mm leg length
 on top.



ANSWERS FOR EXERCISE S.W.I No1

WELD No 17

Square butt weld, welded all way round,
cap reinforcement convexed.



WELD No 18

ARROW SIDE: Single "U" butt weld.



WELD No 19

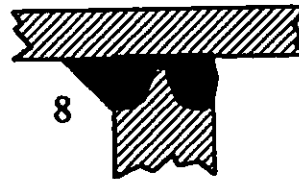
ARROW SIDE: Backing run.

OTHER SIDE: Single "V" butt weld, cap
reinforcement flushed off



WELD No 20

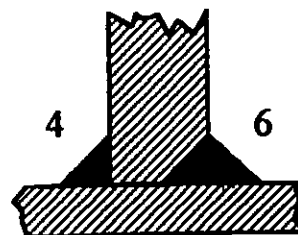
ARROW SIDE: Double "J" butt weld with a
superimposed 8mm leg length fillet weld



WELD No 21

ARROW SIDE: 4mm leg length fillet weld

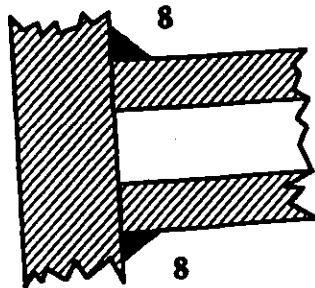
OTHER SIDE: Single bevel butt weld 14mm
depth of penetration, 6mm root face with a
6mm leg length fillet weld superimposed



ANSWERS FOR EXERCISE S.W.I. No1

Q No 11

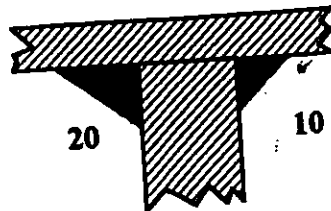
g length fillet weld, welded all way



Q No 12

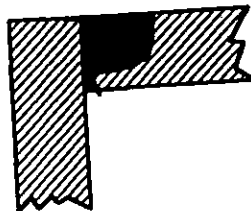
OW SIDE: 20mm leg length fillet weld, throat thickness.

EL SIDE: 10mm leg length fillet weld throat thickness.



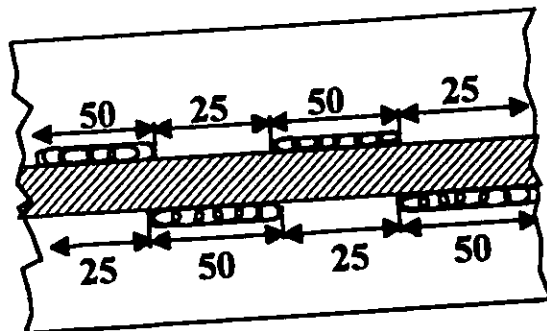
Q No 13

OW SIDE: Single bevel "J" butt weld, using the M.A.G. process.



Q No 14

lded both sides, 6mm leg length fillet welds, in length, 25mm gaps between each weld, ggered.



Q No 15

ROW SIDE: Backing run flushed off. I ER SIDE: Single "V" butt weld 8mm pth of penetration, 4mm root face.



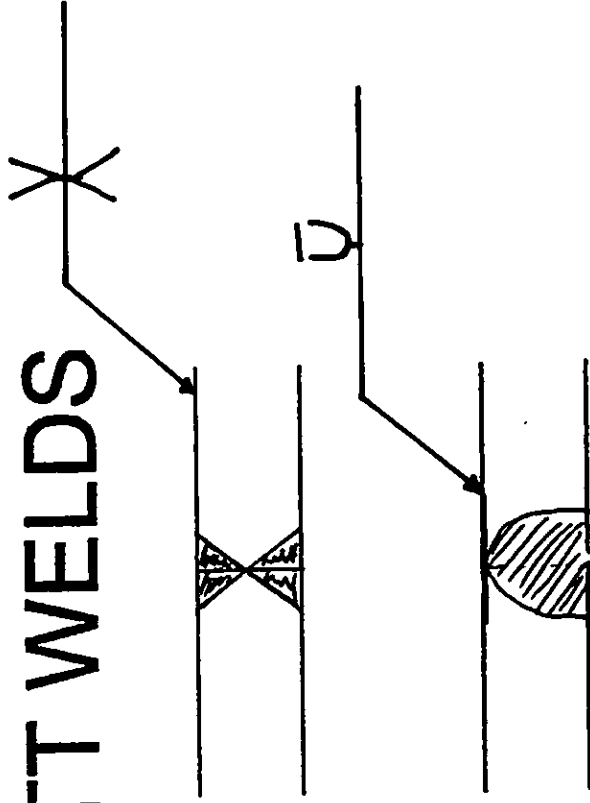
Q No 16

ROW SIDE: Single "J" butt weld, cap e rforcement flushed off.

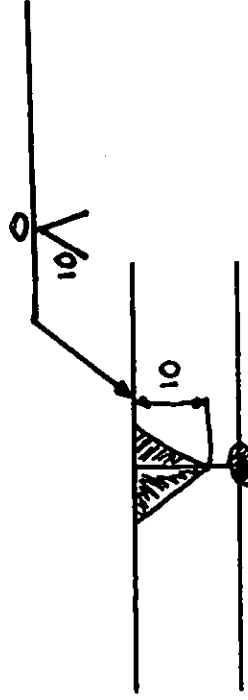


BS 499 prt 2 BUTT WELDS

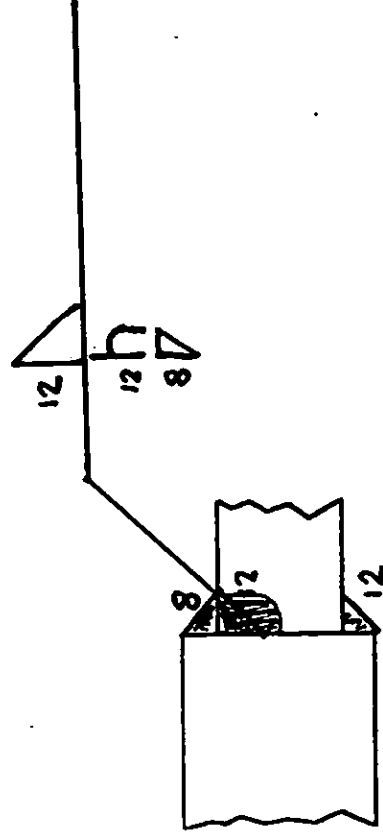
1: DOUBLE "V" BUTT WELD.



2: WELDED OTHER SIDE: SINGLE "U" BUTT WELD, CAP REINFORCEMENT FLUSH.



3: WELDED ARROW SIDE: SINGLE "V" BUTT WELD, DEPTH OF PENETRATION 10mm WELDED OTHER SIDE: BACKING RUN.

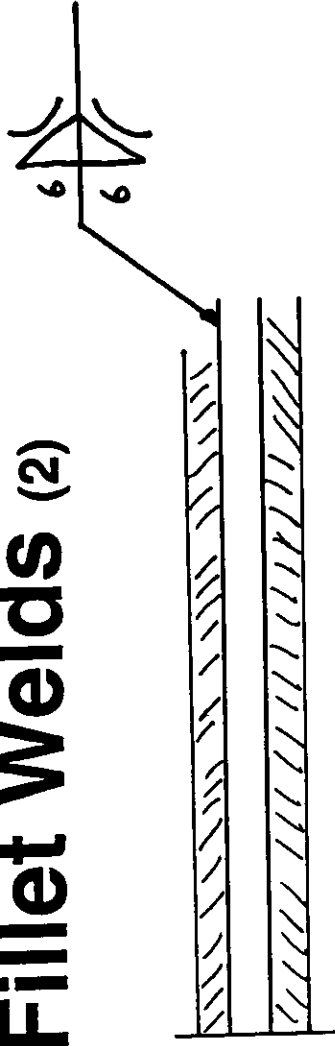


4: ARROW SIDE: SINGLE BEVEL "J" DEPTH OF PENETRATION 12mm WITH A 8mm LEG LENGTH FILLET WELD SUPERIMPOSED WELDED OTHER SIDE: 12mm LEG LENGTH FILLET

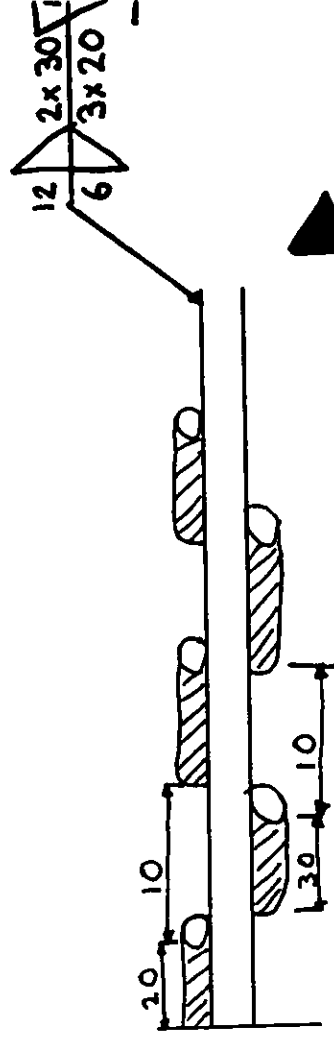
BS 499 : Part 2 : Fillet Welds (2)

Leg.

- A continuous concave fillet weld, 6 mm lengths welded both sides.



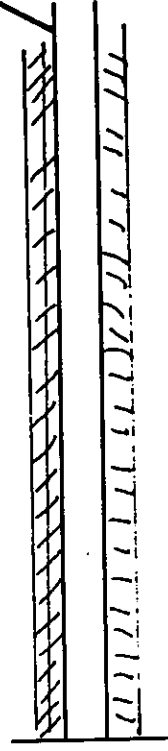
- Welded arrow side: Three intermittent fillet welds, 6 mm leg lengths, the length of each weld 20 mm, the distance between each weld 10 mm.



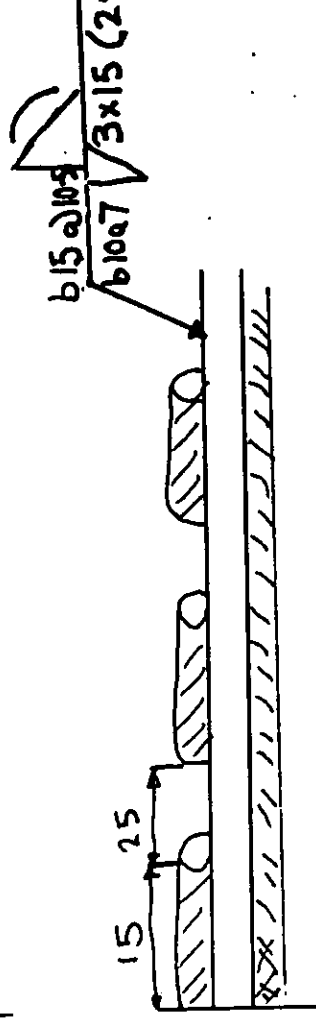
- Welded other side: Two intermittent fillet welds 12 mm leg lengths, the length of each weld 30 mm, the distance between each weld 10 mm. Welds to be staggered.



- A continuous fillet weld, 6 mm leg length, 4 mm throat thickness welded both sides. Welds to be carried out on site.



- Welded arrow side: Three intermittent fillet welds 10 mm leg length, 7 mm throat thickness, length of each weld 15 mm, the distance between each weld 25 mm.

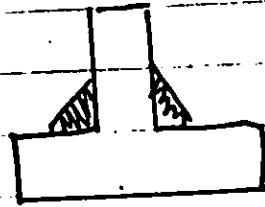
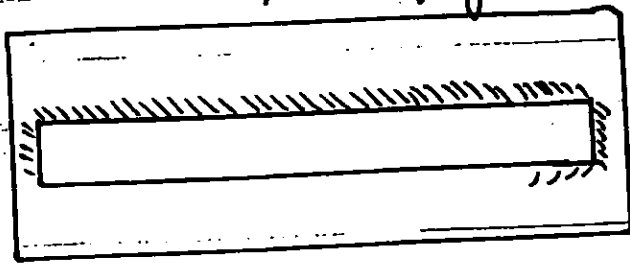


- Welded other side: A continuous convex fillet weld, 15 mm leg length, 10.5 mm throat thickness.

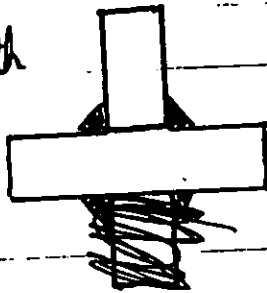


SWI - Exercise N°2.

Fillet weld on 6mm. , it is fully welded all way round on site.



2) 6mm fillet weld welded both sides all way round.



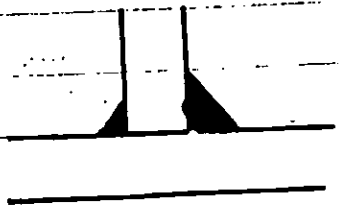
3) Arrow side :- Single Bevel Butt 20mm deep, with 8mm fillet weld superimposed.
Other side :- 10mm Leg length fillet weld.



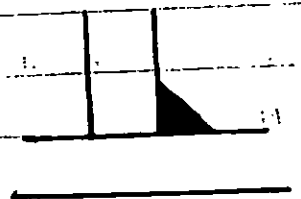
4) 8mm Leg length fillet weld welded arrow side
intermittent fillet welds which are 80mm lg
with 80mm spacing and a 8mm leg length.



5) Arrow side :- Fillet weld with 16mm Leg length
Other side :- " " " 6mm " "



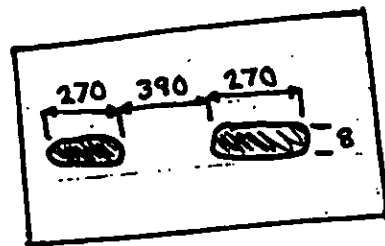
6) Arrow side :- Fillet weld with 8mm Leg length



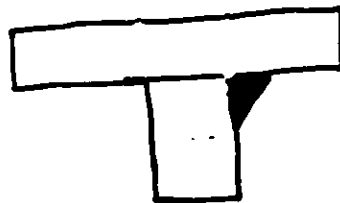
7) Single Bevel Butt on arrow side ground flush.



Arrow Side :- ~~8mm wide~~
 2 welds 270mm lg with 390mm gap,
 & an 8mm wide slot.



6mm leg length fillet weld on arrow side.



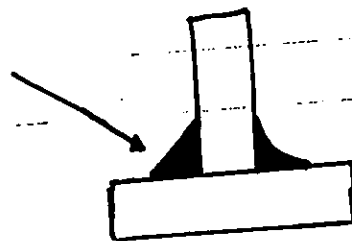
single 'V' prep ground flush on arrow side.



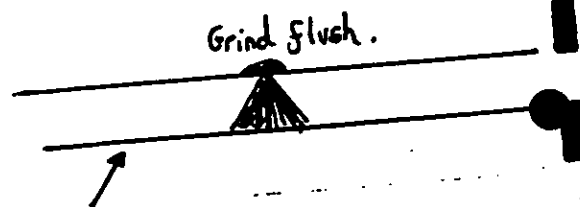
Arrow side :- Square butt ~~convex~~ ^{concave} cap.
 Other side :- Fillet weld, 6mm leg length.



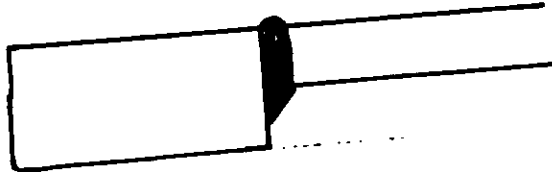
Arrow side :- Fillet weld, 8mm leg length.
 Other side :- Fillet weld, 6mm leg length, concave.



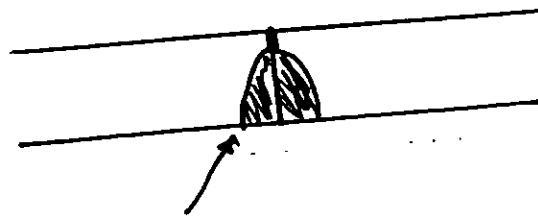
3) Single 'V' on arrow side with a beveling run from other side which is ground flush.



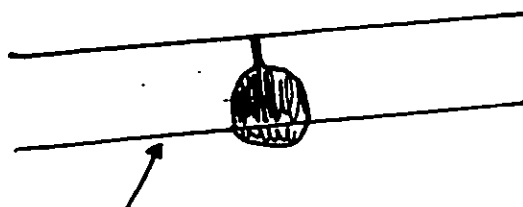
4) Arrow side :- Square butt, convex cap.
 Other side :- Fillet weld, 6mm leg length.



5) Single 'U' with broad face ground flush on arrow side.



16) Single 'U' with broad face on arrow side



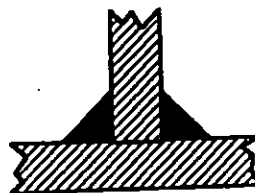
7.) 8mm leg length fillet weld on
arrow side



ANSWERS FOR EXERCISE S.W.I 2

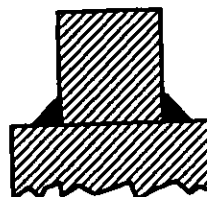
WELD No 1

5mm leg length fillet weld, welded all way round, welded on site.



WELD No 2

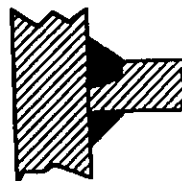
6mm leg length fillet weld, welded all way round.



WELD No 3

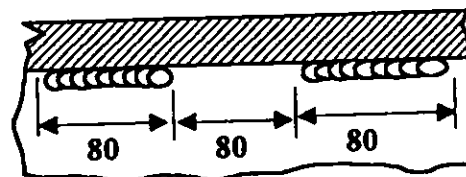
ARROW SIDE: 10mm leg length fillet weld.

OTHER SIDE: Single "J" butt weld, depth of penetration 20mm, 10mm root face, 8mm leg length fillet weld superimposed.



WELD No 4

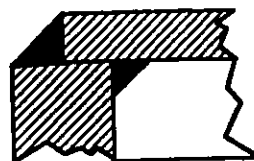
ARROW SIDE: 8mm leg length fillet welds, space welded 10 welds in total, 80mm long, 80mm gaps between each weld.



WELD No 5

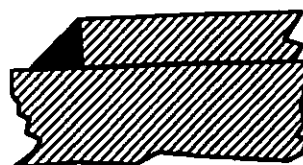
ARROW SIDE: 16mm leg length fillet weld.

OTHER SIDE: 6mm leg length fillet weld



WELD No 6

ARROW SIDE: 8mm leg length fillet weld.



ANSWERS FOR EXERCISE S.W.I. 2

WELD No 14

Same as number 11.

WELD No 15

ARROW SIDE: Single "U" butt weld,
cap reinforcement flushed off.



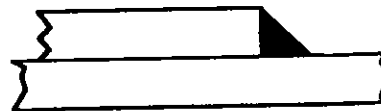
WELD No 16

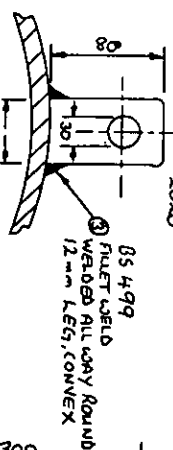
ARROW SIDE: Single "U" butt weld.



WELD No 17

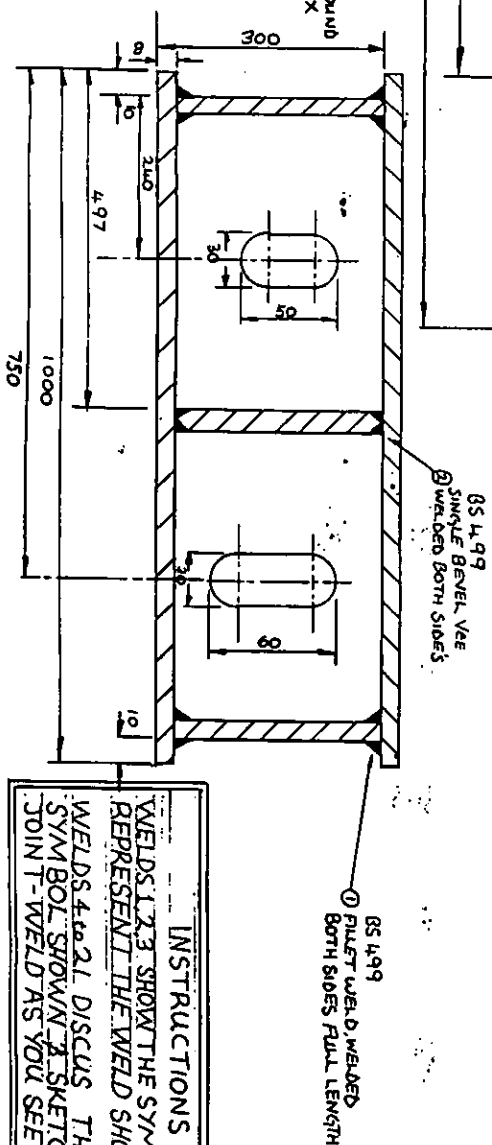
ARROW SIDE: 8mm leg length fillet weld.





ALL FILET WELDS, 8mm LEG LENGTHS
UNLESS OTHERWISE STATED
ALL WELDS TO BE WELDED USING
M.M.A UNLESS OTHERWISE STATED

LIFTING LUGS DETAILS



INSTRUCTIONS

WELDS 4 TO 21 DISCUS THE WELD SYMBOL SHOWN A SKETCH THE JOINT WELD AS YOU SEE IT

FIXED SUPPORT DETAILS

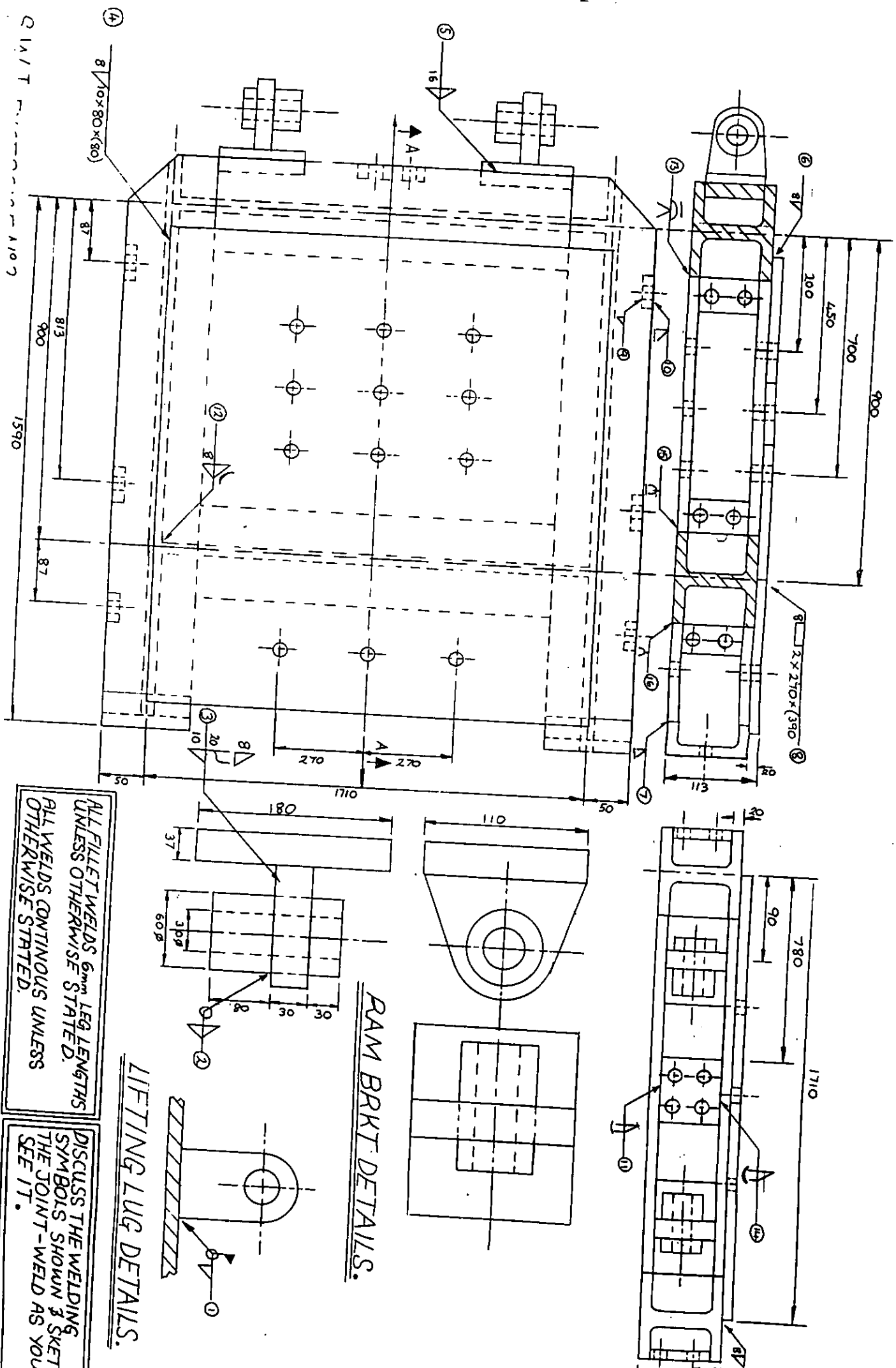
S.W.I. EXERCISE N°1

The first part of the paper discusses the importance of understanding the cultural context of the research. It highlights the need for researchers to be sensitive to the values and beliefs of the communities they are studying. This is particularly important in the field of education, where cultural differences can significantly impact learning outcomes.

The second part of the paper focuses on the methodology used in the study. It describes the process of selecting participants, collecting data, and analyzing the results. The authors emphasize the importance of using a mixed-methods approach to gain a comprehensive understanding of the research topic.

The third part of the paper presents the findings of the study. It discusses the results of the quantitative data analysis and the insights gained from the qualitative interviews. The authors conclude that there are significant differences in learning outcomes between the two groups, and these differences can be attributed to cultural factors.

The final part of the paper discusses the implications of the findings for future research and practice. It suggests that educators should be aware of the cultural context of their students and tailor their teaching methods accordingly. The authors also recommend further research to explore the underlying reasons for the observed differences.



RECORD OF PROFESSIONAL WELDING EXPERIENCE

This section should record the principal features of your job specification for the posts which you have held during the past five years and should show your specific welding responsibilities. Please indicate whether the responsibility is direct or delegated in each case. If more than one post is involved, please photocopy pages and continue.

CURRENT JOB TITLE _____

No. of subordinate staff _____ Employed from (date) _____

Employer _____ No. of employees _____

Principal products/activities _____

Materials involved _____

Welding processes used _____

Codes and standards involved _____

JOB SPECIFICATION Principal features showing welding responsibilities	Welding responsibilities are:	
	Direct	Delegated
Percentage of your time devoted to above welding responsibilities		

ORGANOGRAM

This section should show clearly your position in the organisation related both to senior and subordinate staff and to other staff having welding responsibilities:

Authenticated by (initials) _____

SEM/CSWIP/SS11F/09.98

610468-8001-0-PP+ 88180 8857 01/87

EVIDENCE OF CONTINUING PROFESSIONAL DEVELOPMENT (CPD)

CSWIP Welding and Senior Welding Inspectors are required to keep themselves up-to-date with technical developments in their field. Please provide details in the sections below covering the last five years to support your renewal application with respect to CPD. If you are able to provide an official TWI CPD Personal Record Card with authenticated entries, you do not need to complete this form. Blank Record Cards are available free of charge from TWI Certification Ltd.

Please indicate how you have kept up-to-date with developments in welding technology over the last five years, for example, internal courses, reading journals, external training, Membership of a welding society:

Do you have a personal formal CPD system ? If yes, please give details of what it contains and outline your plan for the next five years

AUTHENTICATION *

Name of responsible person:

Telephone number:

Authenticating signature or stamp:

COMPANY NAME & ADDRESS			
NAME OF RESPONSIBLE PERSON **			
TELEPHONE NUMBER			
Dates of employment			BASIS *
From:	To:		PAYE OR SELF/EMP
BRIEF OUTLINE OF WORK CARRIED OUT FOR THE ABOVE COMPANY (please refer to separate guidance notes)			
			AUTHENTICATING SIGNATURE & STAMP

COMPANY NAME & ADDRESS			
NAME OF RESPONSIBLE PERSON **			
TELEPHONE NUMBER			
Dates of employment			BASIS *
From:	To:		PAYE OR SELF/EMP
BRIEF OUTLINE OF WORK CARRIED OUT FOR THE ABOVE COMPANY (please refer to separate guidance notes)			
			AUTHENTICATING SIGNATURE & STAMP

* delete as applicable

** This person may be telephoned to verify that the work you conducted for him/her was satisfactory and relevant to the certificate for which renewal is sought.

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23/10/1998 08:38 44-0-0-1223-894219

RENEWAL OF CSWIP CERTIFICATES LOG SHEET

(REQUIREMENTS - PAGE 2)

CANDIDATE'S NAME _____

DATE OF BIRTH: _____

COMPANY NAME & ADDRESS		
NAME OF RESPONSIBLE PERSON **		
TELEPHONE NUMBER		
Dates of employment		BASIS *
From:	To:	PAYE OR SELF/EMP
BRIEF OUTLINE OF WORK CARRIED OUT FOR THE ABOVE COMPANY (please refer to separate guidance notes)		
		AUTHENTICATING SIGNATURE & STAMP

COMPANY NAME & ADDRESS		
NAME OF RESPONSIBLE PERSON **		
TELEPHONE NUMBER		
Dates of employment		BASIS *
From:	To:	PAYE OR SELF/EMP
BRIEF OUTLINE OF WORK CARRIED OUT FOR THE ABOVE COMPANY (please refer to separate guidance notes)		
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If yes, please give details of what it contains and outline your plan for the next five years

AUTHENTICATION

Name of responsible person:

Telephone number:

Authenticating signature or stamp:

(REQUIREMENTS)

COMPANY NAME & ADDRESS		
NAME OF RESPONSIBLE PERSON **		
TELEPHONE NUMBER		
Dates of employment		BASIS *
From:	To:	PAYE OR SELF/EMP
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