

WIS 5 Welding Inspection

Section 01

Duties & Responsibilities of a Welding Inspector

Welding Inspection

An Introduction:

In the fabrication industry it is common practice to employ Welding Inspectors to ensure that fabricated items meet minimum specified requirements and will be suitable for their intended applications. Employers need to ensure that Welding Inspectors have appropriate abilities, personal qualities and level of job knowledge in order to have confidence in their work. As a means of demonstrating this there are a number of internationally recognised schemes, under which a Welding Inspector may elect to become certified.

The purpose of this text is to provide supporting **WIS 5 (Welding Inspection of Steel 5)** course reference notes for candidates seeking qualification in the Certification Scheme of Welding and Inspection Personnel **CSWIP 3.1/3.0 Welding Inspectors examinations**.

A competent Welding Inspector should possess a minimum level of relevant experience, and as such there are strict pre-examination experience requirements for the various examination grades. Each prospective CSWIP candidate should ensure their eligibility by evaluating experience requirements prior to applying for any CSWIP examination against the published document **CSWIP-WI-6-92. (Requirements for Certification of Welding Inspectors)** All experience claims should be recorded on an independently verified CV.

A proficient and efficient Welding Inspector would require a sound level of knowledge in a wide variety of quality related technologies employed within the many areas of the fabrication industry. As each sector of industry would rely more on specific processes and methods of manufacture than others, it would be an impossible task to hope to encompass them all in any great depth within this text, therefore the main aim has been to generalise, or simplify wherever possible.

In a typical Welding Inspectors working day a high proportion of time would be spent in the practical visual inspection and assessment of welds on fabrications, and as such this also forms a large part of the assessment procedure for most examination schemes.

BS EN 970 (Non-destructive Examination of Fusion Welds - Visual Examination) is a standard that gives guidance on welding inspection practices as applied in Europe.

The standard contains the following general information:

- Basic requirements for welding inspection personnel.
- Information about conditions suitable for visual examination.
- Information about aids that may be needed/helpful for inspection.
- Guidance about the stages when visual inspection is appropriate.
- Guidance on what information to include in examination records.

It should always be remembered that other codes and standards relating to welding inspection activities exist and may be applied to contract documents.

It could be generally stated that all welding inspectors should be:

- Familiar with the standards, rules and specifications relevant for the fabrication work being undertaken. (This may include National standards, Client standards and the Company's own 'in-house' standards)
- Informed about the welding processes/procedures to be used in production.
- Of high near visual acuity, in accordance with the applied scheme or standard. This should also be checked periodically.

The important qualities/characteristics that proficient Welding Inspectors are expected to have include:

- Honesty
- A good standard of literacy and numeracy
- A good level of general fitness

Welding Inspection is a job that demands the highest level of integrity, professionalism, competence, confidence and commitment, if it is to be carried out effectively. Practical experience of welding inspection in the fabrication industry together with a recognised qualification in Welding Inspection is a route towards satisfying the requirements for competency.

The job of an inspector is not unlike that of a judge in any court of law, in that it falls upon the Inspector to interpret the written word, and which on occasions can be a little grey. A balanced and correct interpretation is a function of **knowledge and experience**, but it must be remembered that it is *not the inspectors job to re-write the specification.*

The scope of work of the Welding Inspector can be very wide and varied, however there are a number of topics that would be common to most areas of industry i.e. most fabrications are produced from drawings, and it is the duty of the welding inspector to check that correct drawings and revisions have been issued for use during fabrication.

The ***Duties of a Welding Inspector*** are an important list of tasks or checks that need to be carried out by the inspector, ensuring the job is completed to a level of quality specified. These tasks or checks are generally directed in the applied ***application standard***. A typical list of a Welding Inspectors duties may be produced which for simplicity can be initially grouped into 3 specific areas:

- 1) Before Welding
- 2) During Welding
- 3) After Welding (Including repairs)

These 3 groups may be expanded to list all the specific tasks or checks that a competent Welding Inspector may be directed to undertake whilst carrying out his/her duties.

It is the *duty of all Welding Inspectors* to ensure all operations concerning welding are carried out in strict accordance with written agreed practices, or specifications.

This will include monitoring or checking a number of operations including:

Before welding:

Safety:

Ensure that all operations are carried out in complete compliance with local, company, or National safety legislation (i.e. permits to work are in place).

Documentation:

Check specification. (Year and revision)

Check drawings. (Correct revisions)

Check welding procedure specifications and welder approvals

} Issued to relevant parties

Validate certificates of calibration. (Welding equipment & inspection instruments)

Check material and consumable certification

Welding Process and ancillaries:

Check welding equipment and all related ancillaries. (Cables, regulators, ovens, quivers etc.)

Incoming Consumables:

Check pipe/plate and welding consumables for size, condition, specification and storage.

Marking out preparation & set up:

Check the:

Correct method of cutting weld preparations. (Pre-Heat for thermal cutting if applicable)

Correct preparation. (Relevant bevel angles, root face, root gap, root radius, land, etc.)

Correct pre-welding distortion control. (Tacking, bridging, jigs, line up clamps, etc.)

Correct level and method of pre heat applied prior to tack welding

All tack welding to be monitored and inspected. (Feathering of tacks may be required)

During welding: Monitor

Weather conditions. (Mainly for site work, welding is *generally* halted when *inclement*)

Pre-heat values. (Heating method, location and control method)

In-process distortion control. (Sequence or balanced welding)

Consumable control. (Specification, size, condition, and any **special treatments**)

Welding processes and all related variable parameters. (Voltage, amperage, travel speed, etc)

Welding **and/or** purging gases. (Type, pressure/flow and control method)

Welding conditions for root run/hot pass and all subsequent run, and inter-run cleaning.

Minimum **and/or** maximum inter-pass temperatures. (Temperature and control method)

Check Compliance with all other variables stated on the approved welding procedure

After welding:

Carry out visual inspection of the welded joint. (Including dimensional aspects)

Check and monitor NDT requirements. (Method, qualification of operator, execution)

Identify repairs from assessment of visual or NDT reports. (**Refer to repairs below**)

Post weld heat treatment (PWHT) (Heating method and temperature recording system)

Re-inspect with NDE/NDT after PWHT. (If applicable)

Hydrostatic test procedures. (For pipelines or pressure vessels)

Repairs:

Excavation procedure. (Approval and execution)

Approval of the NDT procedures (For assessment of complete defect removal)

Repair procedure. (Approval of re-welding procedures and welder approval)

Execution of approved re-welding procedure. (Compliance with repair procedure)

Re-inspect the repair area with visual inspection and approved NDT method

Submission of inspection reports, and all related documents to the Q/C department.

To be fully effective, a Welding Inspector requires a high level of knowledge, experience and a good understanding of the job. This should in turn earn some respect from the welder.

Good Welding Inspectors should carry out their *duties competently*, use their *authority wisely* and be constantly *aware of their responsibilities*.

The main *responsibilities* of a Welding Inspector are:

To Observe



To observe all relevant actions related to weld quality throughout production. This will include a final visual inspection of the weld area.

To Record



To record, or log all production inspection points relevant to quality, including a final map and report sheet showing all identified welding imperfections.

To Compare



To compare all reported information with the acceptance levels/criteria and clauses within the applied application standard.

Submit a final inspection report of your findings to the QA/QC department for analysis and any remedial actions.

WIS 5 Section 1 Exercise:

- 1) List 4 other areas that would generally be covered by a non-destructive examination (NDE) inspection standard for welds?

1 Basic requirements for welding inspection personnel

2 _____

3 _____

4 _____

5 _____

- 2) List other desirable characteristics that all welding inspectors should possess?

1 Knowledge and Experience

2 _____

3 _____

4 _____

5 _____

- 3) List 5 other areas of knowledge with which a proficient welding inspector should be familiar with?

1 Welding Processes

2 _____

3 _____

4 _____

5 _____

6 _____

4) Define your duties as a Welding Inspector to your nominated code of practice.

Target Volume: Approximately 300 words (1.5 – 2 sides of A4 paper)
Target Time: 15-20 minutes

The duties of a welding inspectors are an important list of checks and tasks that need to be carried out by inspector to ensure the jobs completed to a level of quality specified. These duties could be divided into 3 groups as follows:

- 1) Before Welding
- 2) During welding
- 3) After welding

1) Before Welding

- 1-1) Safety: Ensure all operations are according to local company or national safety rules.
- 1-2) Document:
 - check specification (year & revision), drawing (revisions), welding procedure specification, procedure qualification records and welder approvals
 - check validation of calibration certificates (welding equipments & inspection instruments) and certificate of material & welding consumables
- 1-3) Incoming consumable:
 - check plate/pipe and welding consumables for size, condition specification and storage
- 1-4) Welding equipment:
 - check welding equipment and all related accessories (oven, flowmeter, cables, etc)
- 1-5) Preparation and fit up:
 - check correct cutting method (preheat before thermal cutting, if app.)
 - correct preparation (bevel angle, root face, root gap, root radius, land, etc)
 - correct pre welding distortion control (Tacking, bridging, jigs and clamps)
 - All tacking need to be monitored and inspected (featherings)
 - Correct method & level of pre heat applied before tack welding

2) During welding: Monitor

WIS 5 Welding Inspection

Section 02

Terms & Definitions

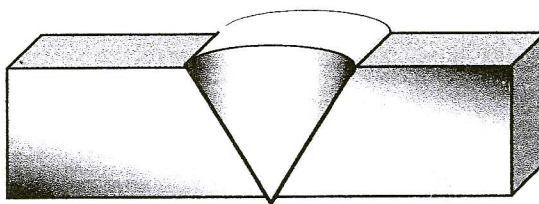
Terms and Definitions:

A Weld: *A Union of Materials Caused by Heat and/or Pressure*
i.e. "The Process of Welding"

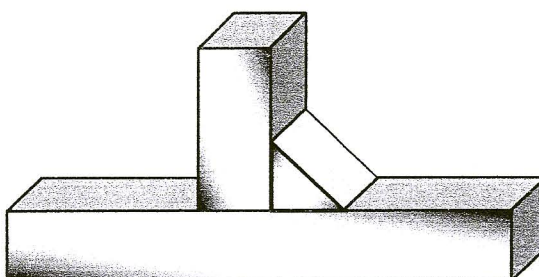
A Joint: *A Configuration of Members*
In this sense "To be Welded"

Types of common welds

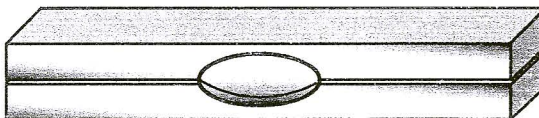
Butt Welds



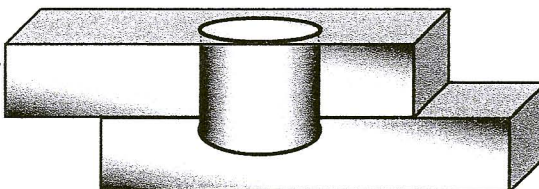
Fillet Welds



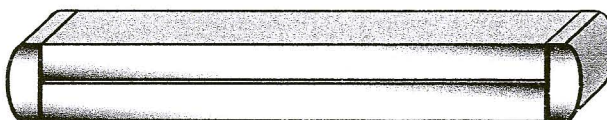
Spot/Seam Welds



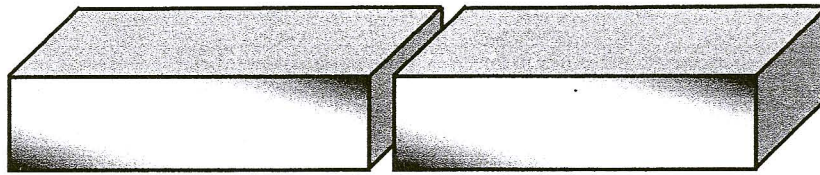
Plug/Slot Welds



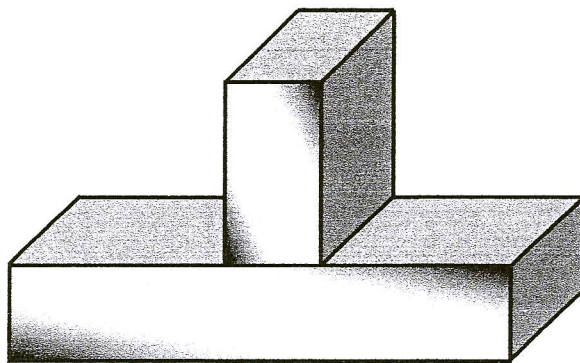
Edge Welds



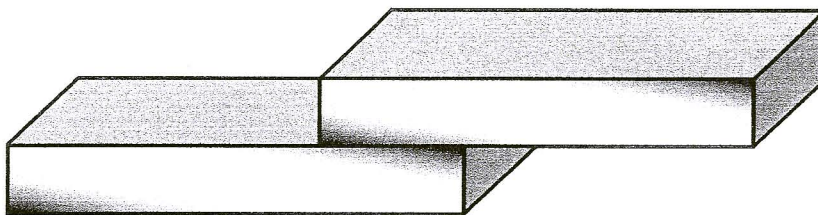
Types of common joints



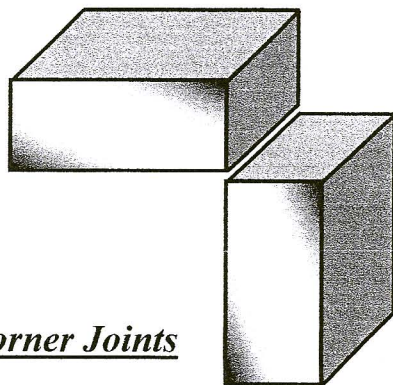
Butt Joints



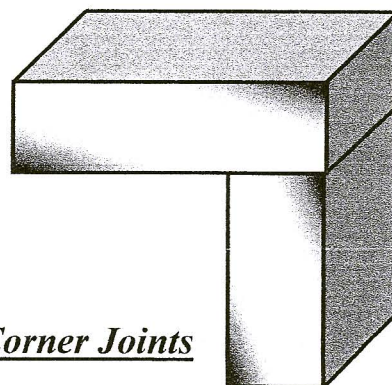
T Joints



Lap Joints



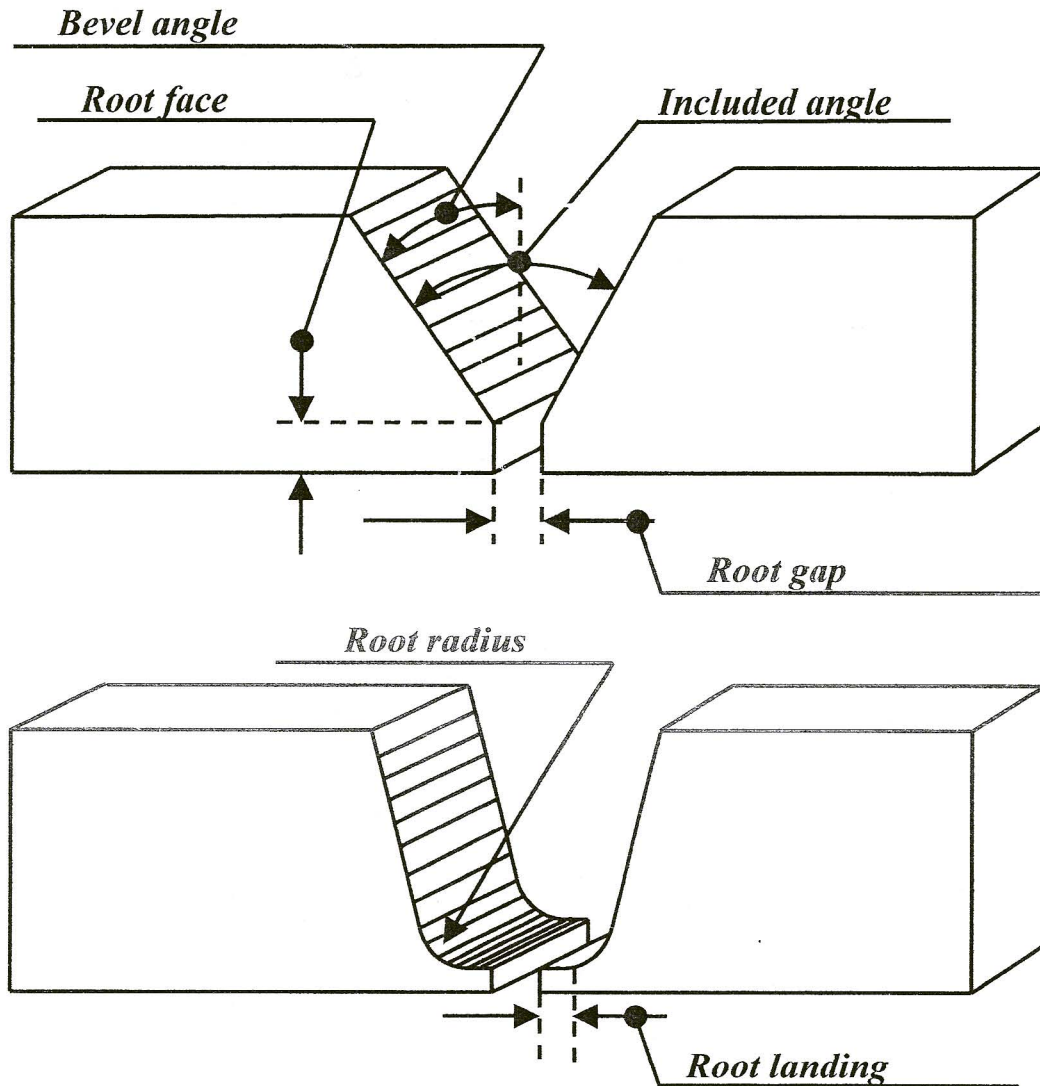
Open Corner Joints



Closed Corner Joints

Weld Preparations

When welding, we need to fully fuse the entire width of the faces of both members. Mostly, we need to *prepare* or remove metal from the joint to allow *access* for the process, for full *fusion* of the faces. Grinding, flame/arc cutting, or machining for this operation, but grinding back 1 or 2 mm may be required after flame/arc cutting.

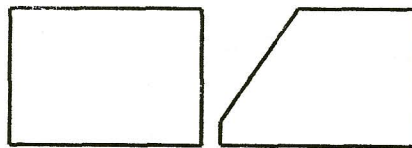


The purpose of a weld preparation is to allow access for the welding process, penetration and fusion through the complete area of the joint and its faces. The function of the root gap is to allow penetration. The function of the root face is to remove excess heat and act as a heat sink. The higher the arc energy of the process, then generally the wider is the root face.

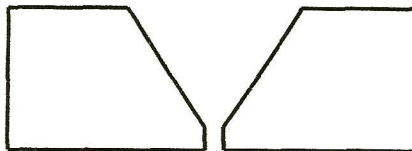
The simple rule is this: *The more taken out then the more must be replaced.*

Single Sided Butt Weld Preparations

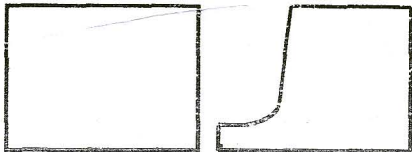
Single Bevel



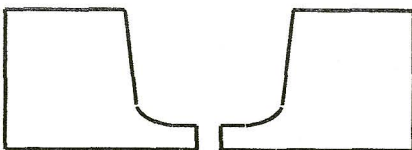
Single V



Single J



Single U

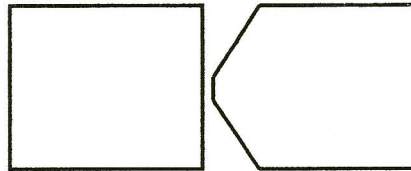


Single sided preparations are normally made on thinner materials, or when access from both sides is restricted.

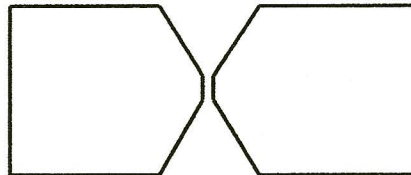
The selection may be also influenced by the capability of the welding process and the position of the joint, or the positional capability of available welding consumables, or the skill level available.

Double Sided Butt Weld Preparations

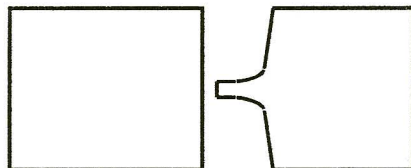
Double Bevel



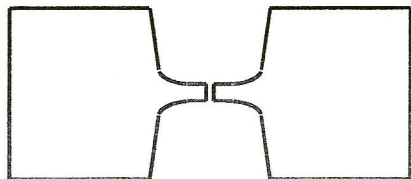
Double V



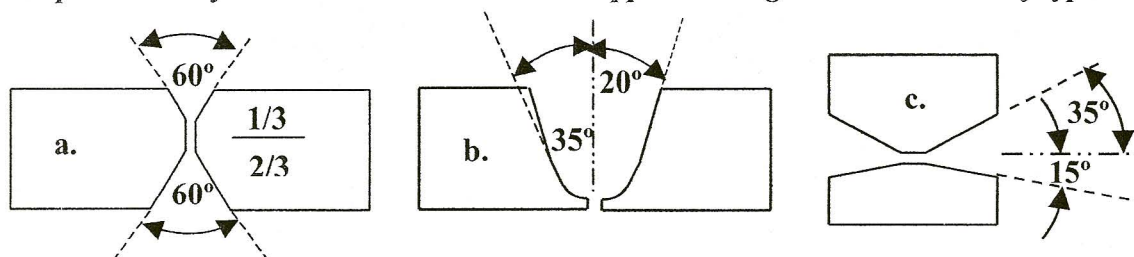
Double J



Double U

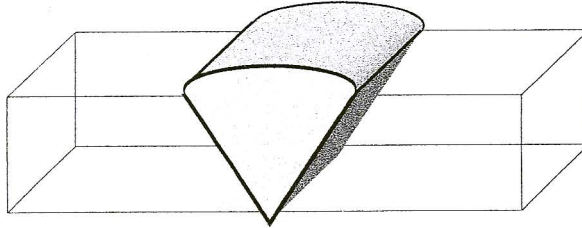


Double sided preparations are normally made on thicker materials, and when access from both sides is **unrestricted**. They may also be used to control the effect of distortion, and in controlling economics, by reducing weld volume when welding thicker sections. It should be noted that it is not uncommon to find weld preparations that are of a *compound* or *asymmetrical* nature. *Values & applications given below are only typical:*

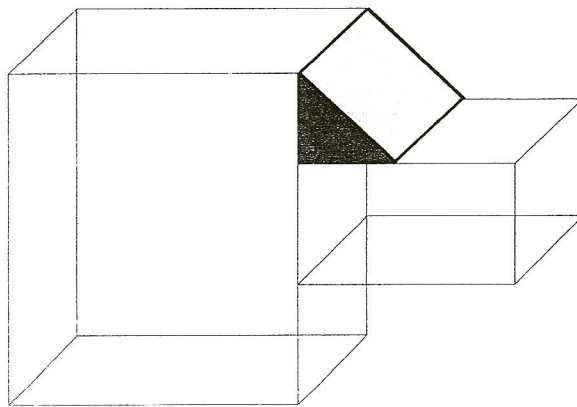


- An *asymmetrical 1/3 + 2/3* preparation, sometimes used to control/reduce the effect of contraction/distortion where access to sides is restricted. The 1/3 is welded first.
- A *compound angle* preparation, used to reduce weld metal costs in thicker section. *Unrestricted*
- An *asymmetrical bevel* preparation, sometimes used in positional welding.

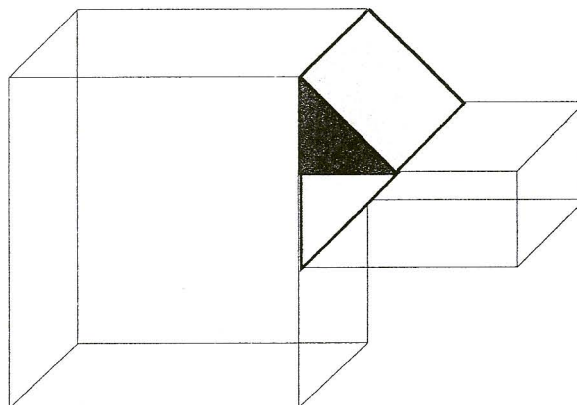
Welded Butt Joints



A Butt Welded Butt Joint

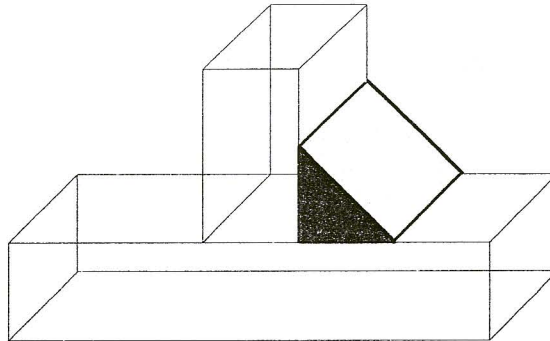


A Fillet Welded Butt Joint

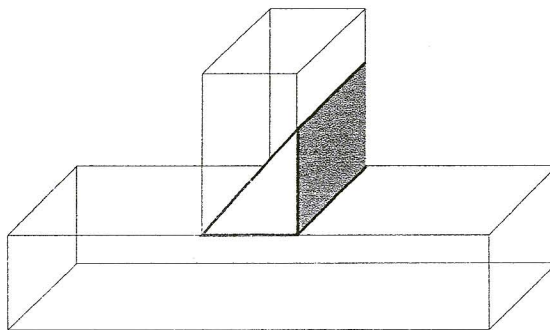


A Compound Welded Butt Joint

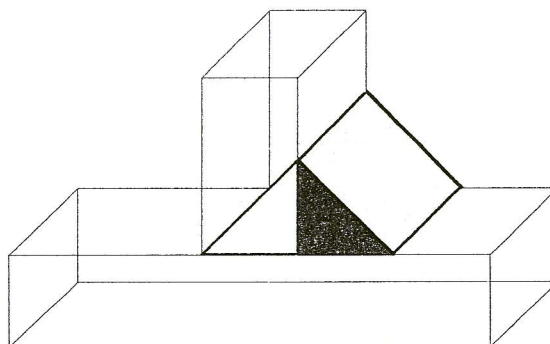
Welded T Joints



A Fillet Welded T Joint

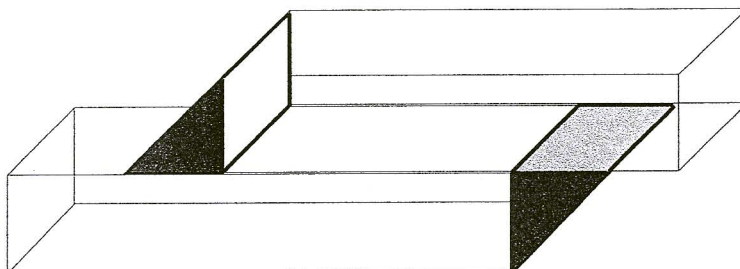


A Butt Welded T Joint

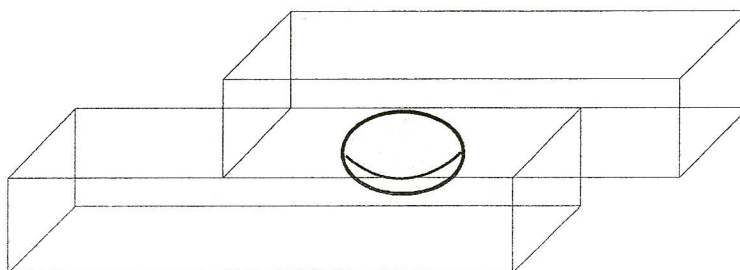


A Compound Welded T Joint

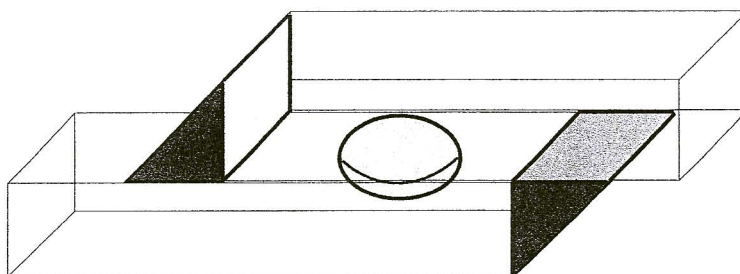
Welded Lap Joints



A Fillet Welded Lap Joint

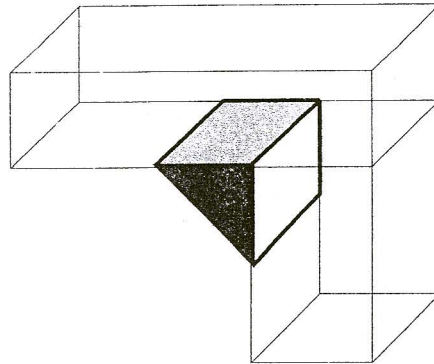


A Spot Welded Lap Joint

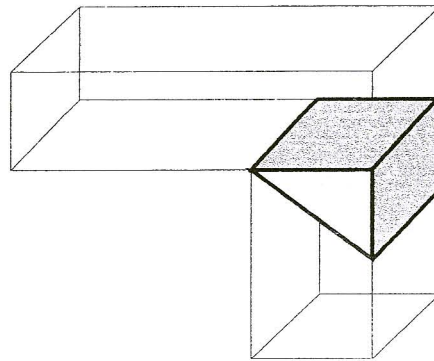


A Compound Welded Lap Joint
(Not commonly used)

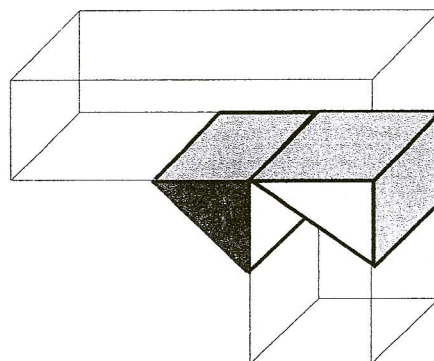
Welded Closed Corner Joints



A Fillet Welded Closed Corner Joint

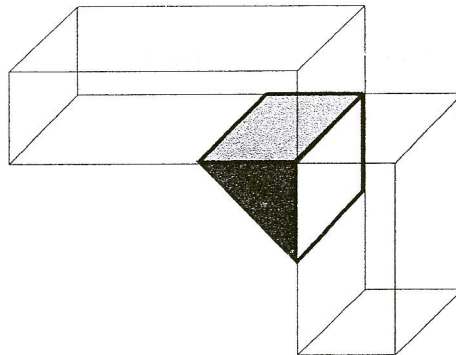


A Butt Welded Closed Corner Joint

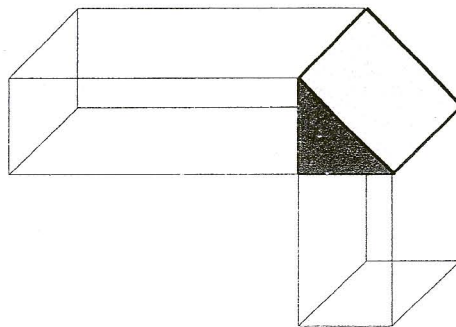


A Compound Welded Closed Corner Joint

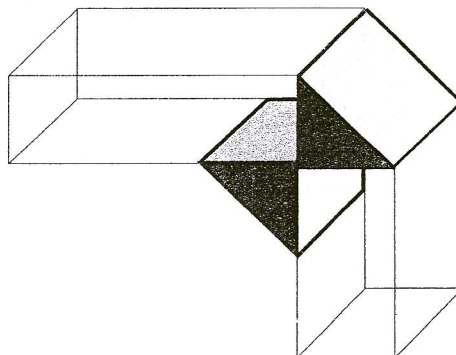
Welded Open Corner Joints



An Inside Fillet Welded Open Corner Joint



An Outside Fillet Welded Open Corner Joint



A Double Fillet Welded Open Corner Joint

WIS 5 Welding Inspection

Section 03

Welding Imperfections

Welding Imperfections:

What are welding imperfections?

Welding imperfections are discontinuities caused by the *process of welding*.

All things contain imperfections, however it is only when they fall outside of an applied "*level of acceptance*" that they should be termed *defects*, as they may then render the product *defective* or unfit for its purpose. The closeness of tolerance in an applied level of acceptance depends largely upon the application and/or the level of quality required.

As all fusion welds can be considered as *castings* they may contain imperfections associated with the casting of metals, plus any other particular imperfections associated with the specific welding process being used.

Welded components can have imperfections, which can be classified as follows:

- | | |
|-------------------------------|-------------------------------------|
| 1) Cracks | 2) Gas pores and cavities |
| 3) Solid inclusions | 4) Lack of fusion |
| 5) Surface and profile | 6) Mechanical/Surface damage |
| 7) Misalignment | |

1) Cracks

Cracks sometimes occur in welded materials, and may be caused by a great number of factors. Generally, we can say that for any crack like imperfection to occur in a material, there are 3 criteria that must be present:

- XXX
- | | | |
|-------------------|---------------------|--------------------------------|
| a) A force | b) Restraint | c) A weakened structure |
|-------------------|---------------------|--------------------------------|

Typical types of hot and cold cracks that will be discussed later in the course are:

- XXX
- | | | |
|--------------------------------|---------------------------------|--------------------------|
| 1) H₂ Cracks | 2) Solidification Cracks | 3) Lamellar Tears |
|--------------------------------|---------------------------------|--------------------------|

A Material's likelihood to crack during welding can be evaluated under the term **Weldability**. This may be defined as:

XX "The ease with which materials may be welded by the common welding processes"

All cracks have sharp edges, which produce high stress concentrations. This generally results in rapid progression, however this also depends on the properties of the metal.

XX Cracks are classified as *planar* imperfections as they generally have only 2 visible, or measurable dimensions i.e. length and depth. Most fall into the defects category, though some standards will allow a degree of so called "*crater, or star*" cracking.

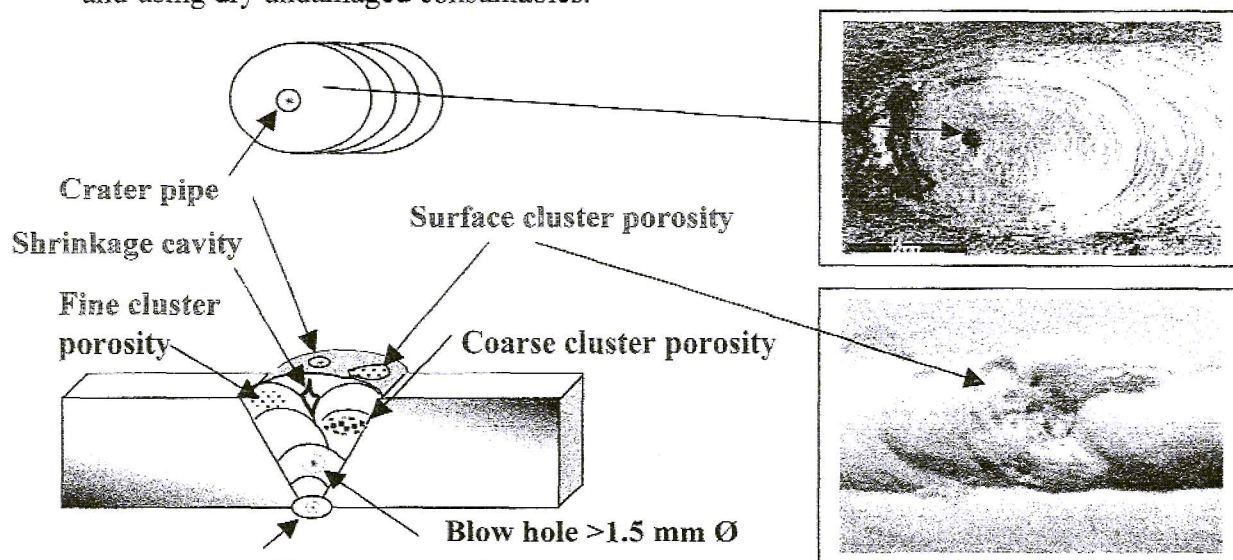
2) Gas pores, porosity, cavities and pipes

Gas pores

These are singular gas filled cavities $\leq 1.5\text{mm}$ diameter, created during solidification of the weld and the expulsion or evolution of gases from solution in solidifying weld metal.

They are generally **spherical** in appearance though they may extend to form **elongated** gas cavities, or **Worm holes** depending on the conditions of solidification. The term used to describe an areas of rounded gas pores is **Porosity**, which may be further classified by the number, size and grouping of the pores within the area (i.e. Fine, or coarse cluster porosity) Gases may be formed by the breakdown of paints, oil based products, corrosion or anti corrosion products that have been left on the plates to be welded. A singular gas filled cavity of $>1.5\text{mm}$ diameter is termed a **Blow hole** Porosity can occur during the

XX MIG or TIG process by the temporary loss of gas shielding, and/or ingress of air into the arc column and may also be caused by an incorrect setting of the shielding gas flow rate. Gas pores/porosity may also break the welds surface where they are known as surface porosity. Porosity may be found in deep SAW or MMA welds due to damp fluxes or damaged MMA electrode coatings. Porosity may be prevented by correct cleaning of materials, correct setting and shielding when using the TIG or MIG welding processes, and using dry undamaged consumables. XXX



Hollow root bead (Elongated Gas Cavity)

Shrinkage cavities

These are internal voids or cavities that are generally formed during the solidification of large single welds of high depth to width ratio ($d:w$) as with SAW or MIG/MAG. They may be defined as **hot plastic tears** caused by large opposing contractional forces in the weld and HAZ until the ductility of the hot metal is overcome resulting in a tear. Shrinkage cavities can produce high concentrations of stress at their sharp edges, which may propagate cracks to the weld surface appearing around the weld centreline.

Crater Pipes

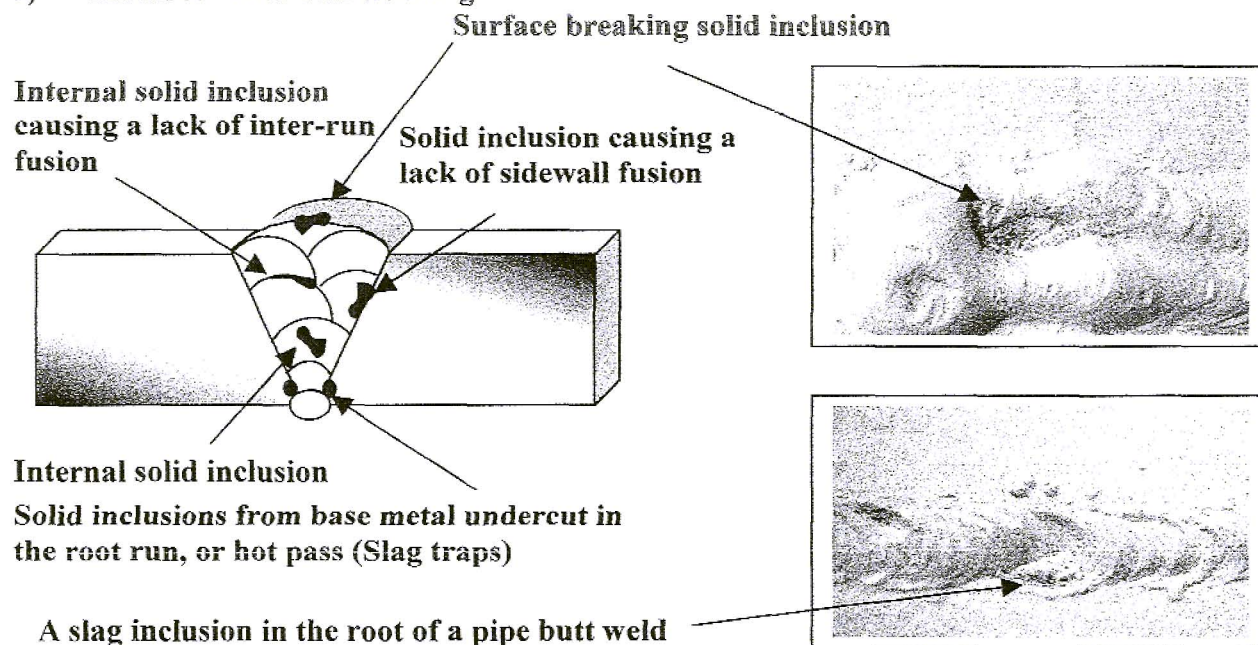
Caused at the end of a weld run, where insufficient filler metal is applied to fill the crater.

3) Solid inclusions

Solid inclusions can be **metallic** or **non-metallic** that are trapped in the weld. The type of solid inclusion is really dependant on the welding process being used. In welding processes that use fluxes to form all the required functions of shielding and chemical cleaning, such as **MMA** and **SAW**, slag inclusions may occur. Other welding processes such as **MIG/MAG** and **TIG** use silicon, aluminium and other elements to de-oxidise the weld. These may form silica, or alumina inclusions. Any of these non-metallic compounds may be trapped inside a weld. This may happen when slag traps, such as undercut have been formed. Slag traps are mostly caused by *incorrect welding technique*. Tungsten inclusions are metallic inclusions, which may be introduced during **TIG** welding by a poor welding technique, an incorrect tungsten vertex angle, or too high amperage for the diameter of tungsten being used. Copper inclusions may be caused during **MIG/MAG** welding by a lack of welding skill, or incorrect settings in mechanised, or automated **MIG** welding. (Mainly welding aluminium alloys)

Welding phenomena such as "**Arc Blow**" or the movement of the electric arc by magnetic forces can cause solid inclusions to be trapped in welds. The locations of these inclusions may be within the centre of a deposited weld, or between welds where the result causes "Lack of inter-run fusion", or at the sidewall of the weld preparation causing "Lack of side wall fusion" Generally solid internal inclusions may be caused by:

- 1) **Lack of welder skill. (Incorrect welding technique)**
- 2) **Incorrect parameter settings, i.e. voltage, amperage, speed of travel**
- 3) **Magnetic arc blow**
- 4) **Incorrect positional use of the process, or consumable**
- 5) **Incorrect inter-run cleaning**



4) Lack of fusion

Lack of fusion imperfections, are defined as a lack of union between two adjacent areas of material. This may be accompanied or caused by other imperfections as explained in the last section. Lack of fusion can be considered a serious imperfection, as like cracks, they produce areas of high stress concentration. Lack of fusion, or overlap (a form of lack of fusion) may occur in the weld face area during positional welding caused by the action of gravity and incorrect use of the process. Lack of fusion may be found in welds where processes using high currents have been used as the arc may be deviated away from the fusion faces causing a lack of fusion in that area of the weld. This effect is known as *Arc blow* and is caused by electro-magnetic force within the arc and material.

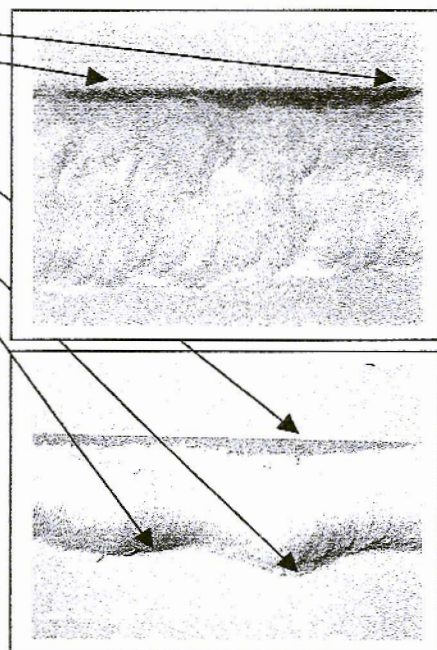
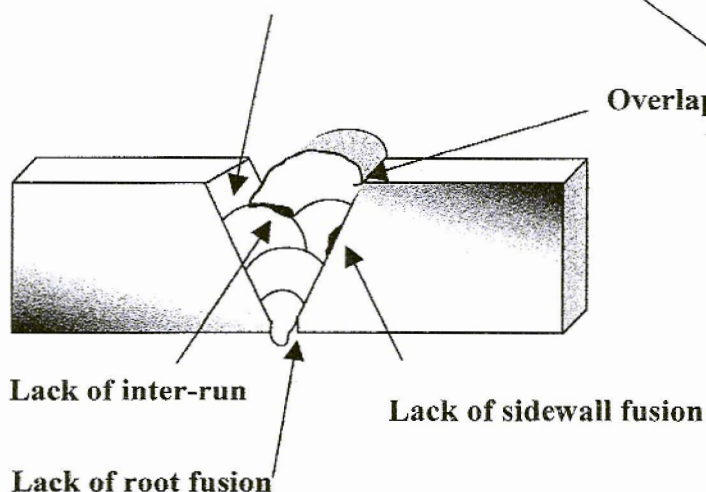
Lack of fusion may also be formed in the root area of the weld where it may be found on one or both plate edges. It may also be accompanied by incomplete root penetration. Lack of sidewall fusion is commonly associated with "Dip transfer MIG welding" of metals of over 3mm thickness, particularly in the vertical down position. This is mainly caused by the inherent coldness of this form of metal transfer, and the action of gravity, but may also be attributed to incorrect settings and a possible lack of welder skill.

Like solid inclusions, lack of fusion imperfections may be caused by:

- 1) Lack of welder skill. (Incorrect welding technique)
- 2) Incorrect parameter settings i.e. voltage, amperage, speed of travel etc
- 3) Magnetic arc blow
- 4) Incorrect positional use of the process, or consumable
- 5) Insufficient inter-run cleaning

Lack of sidewall fusion

(Also causing an Incompletely filled groove)



5) Surface and profile

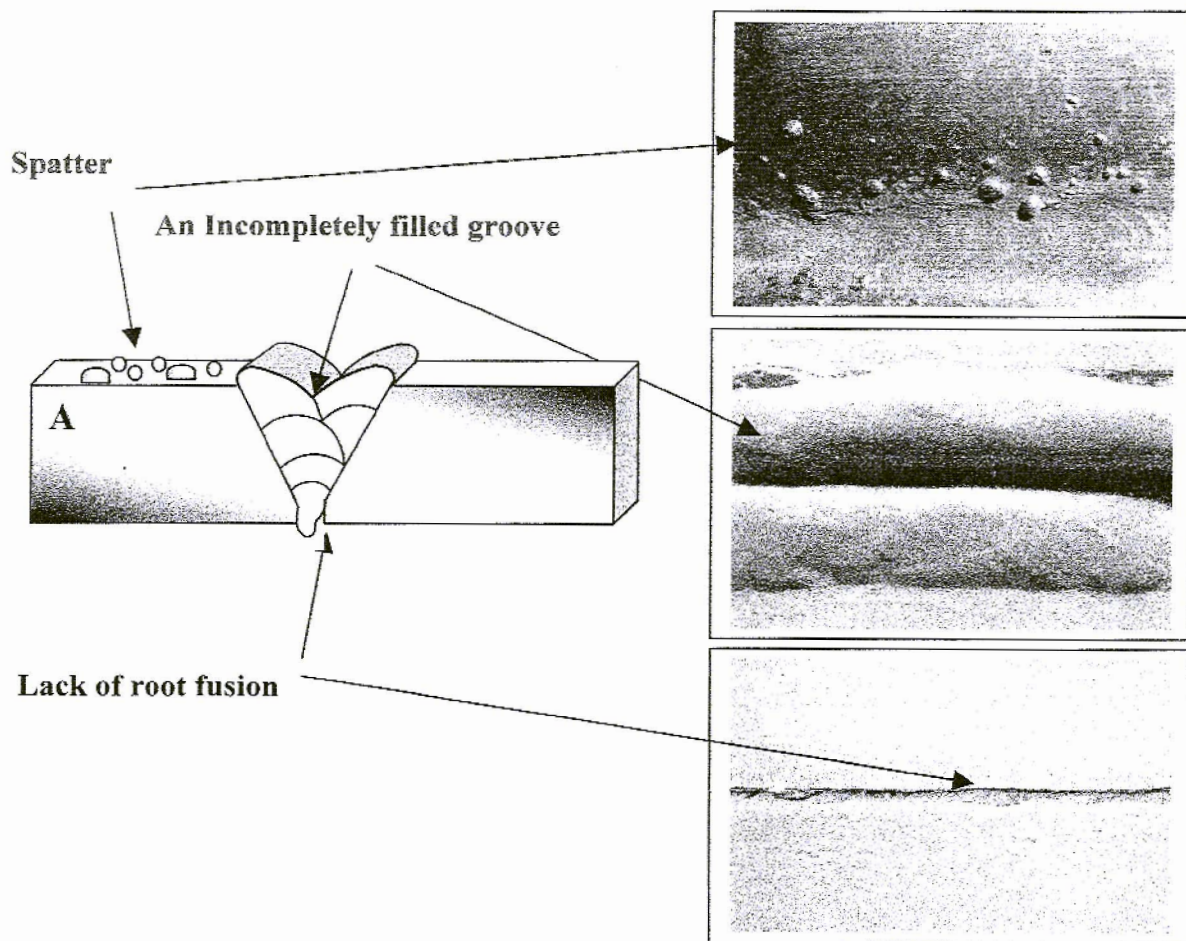
Surface and profile imperfections are generally caused by poor welding techniques. This includes the use of incorrect welding parameters, electrode/blowpipe sizes and/or manipulation and joint set up. This category may be split into two further groups of weld face and weld root. These imperfections are shown pictorially in **A B & C** below:

A:

Spatter is not a major factor in lowering the weldments strength, though it may mask other imperfections, and should therefore be cleaned off before inspection. Spatter may also hinder NDT and be detrimental to coatings. It can also cause micro cracking or hard spots in some materials due to the localised heating/quenching effect.

An incompletely filled groove will bring the weld below the **DTT** (*Design Throat Thickness*) and may also cause a high stress concentration to occur. (Ref. Page 3.4)

Lack of root fusion may cause serious stress concentrations to occur in the root area of the weld. It may be caused by poor a welding technique, Hi – Lo, or irregular weld preparation i.e. Changes in root face thickness.

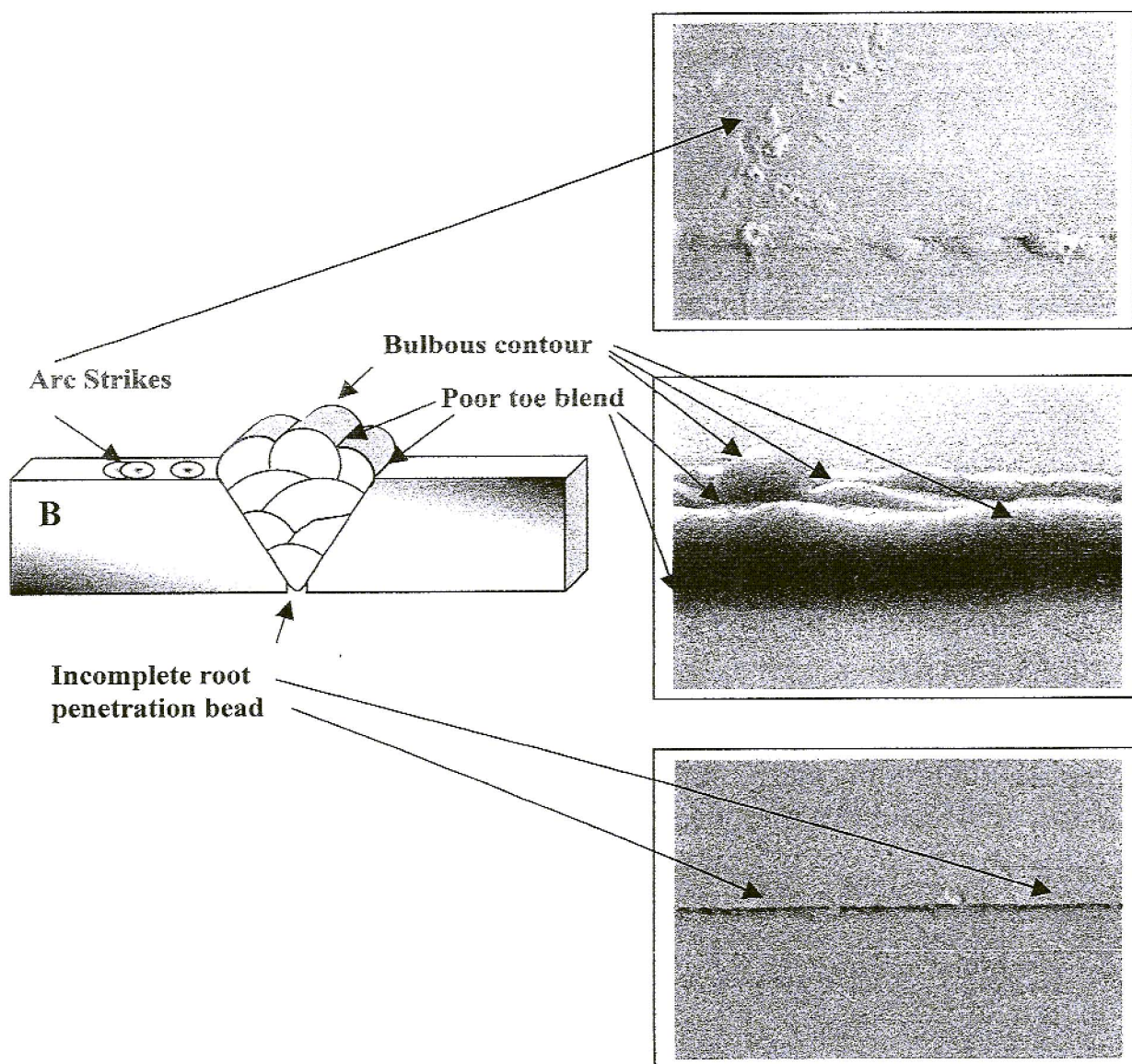


B:

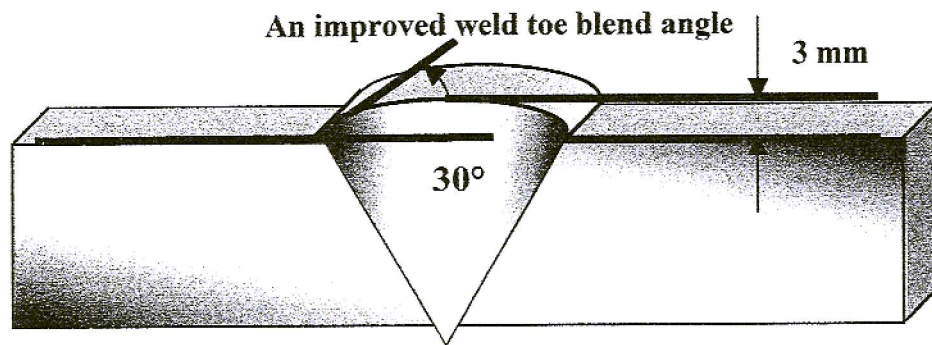
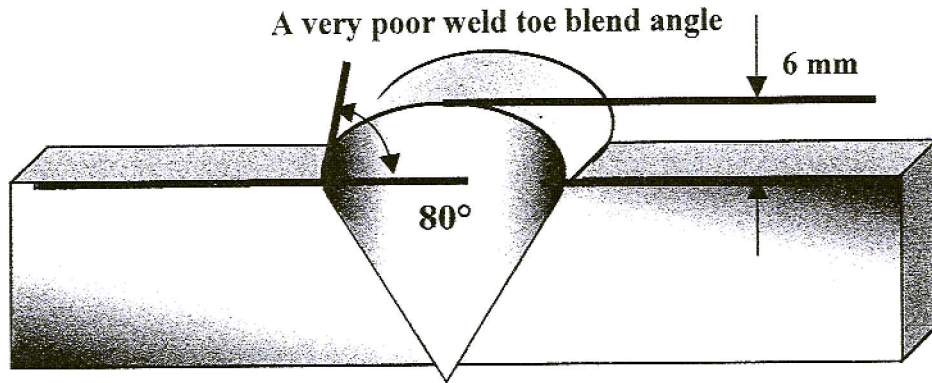
A **bulbous contour** is an imperfection as it causes sharp stress concentrations at the toes of individual passes and may also contribute to overall *poor toe blend*.

Arc strikes, Stray-arcing, or Stray flash may cause many problems including cracks to occur. They can also cause depressions in the plate bringing it below the **DTT**. Arc strikes are normally ground; then crack detected and repaired as required.

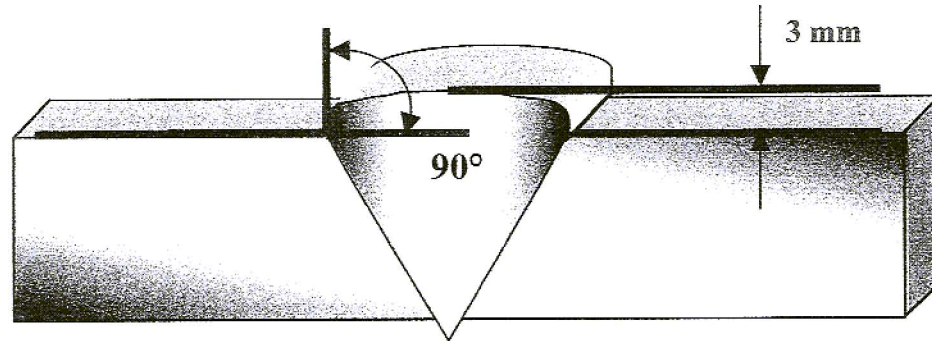
Incomplete root penetration may be caused by too small a root gap, insufficient amperage, or poor welding technique. It may also appear in welding at the end of a poorly dressed or feathered tack weld. It produces sharp stress concentrations, and welds often having a lower ATT (*Actual Throat Thickness*) than that specified for the joint.



Effect of a Poor Toe Blend



The excess weld metal height is within limits but the toe blend angle is unacceptable

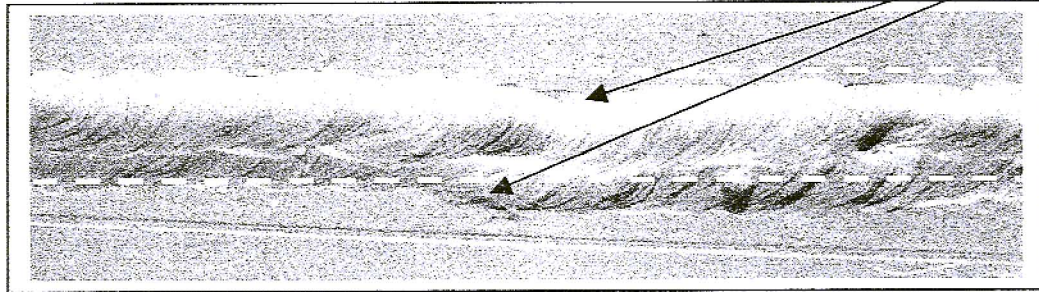


Generally many specifications tend to quote that *"The weld toes shall blend smoothly"* This statement can cause many problems as it is not a **quantitative** statement, and therefore very much open to individual interpretation. To help in your assessment of the acceptance of the toe blend it should be remembered that the higher the angle at the toe then the higher is the concentration of stresses.

A poor toe blend **will** be present when the excess weld metal height is excessive or the weld profile is excessively bulbous, however it may be possible that the height is within the given limits, yet the toe blend is not smooth, and is therefore a defect, and unacceptable. It should also be remembered, that a poor toe blend in the root of the weld has the same effect. It can be clearly seen that any rapid change in the section will induce stress concentration and therefore the use of the term **reinforcement** to describe any amount of excess weld metal is very misleading and inaccurate, though this term is very often used in many application standards.

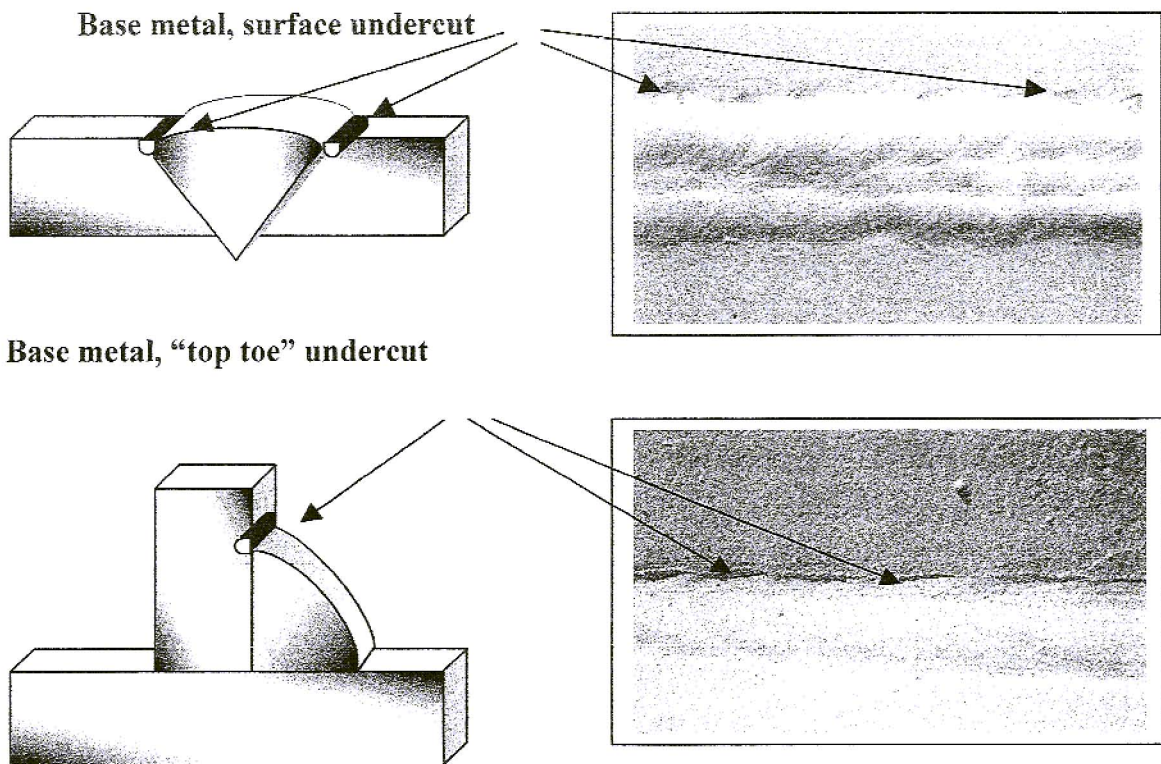
C:

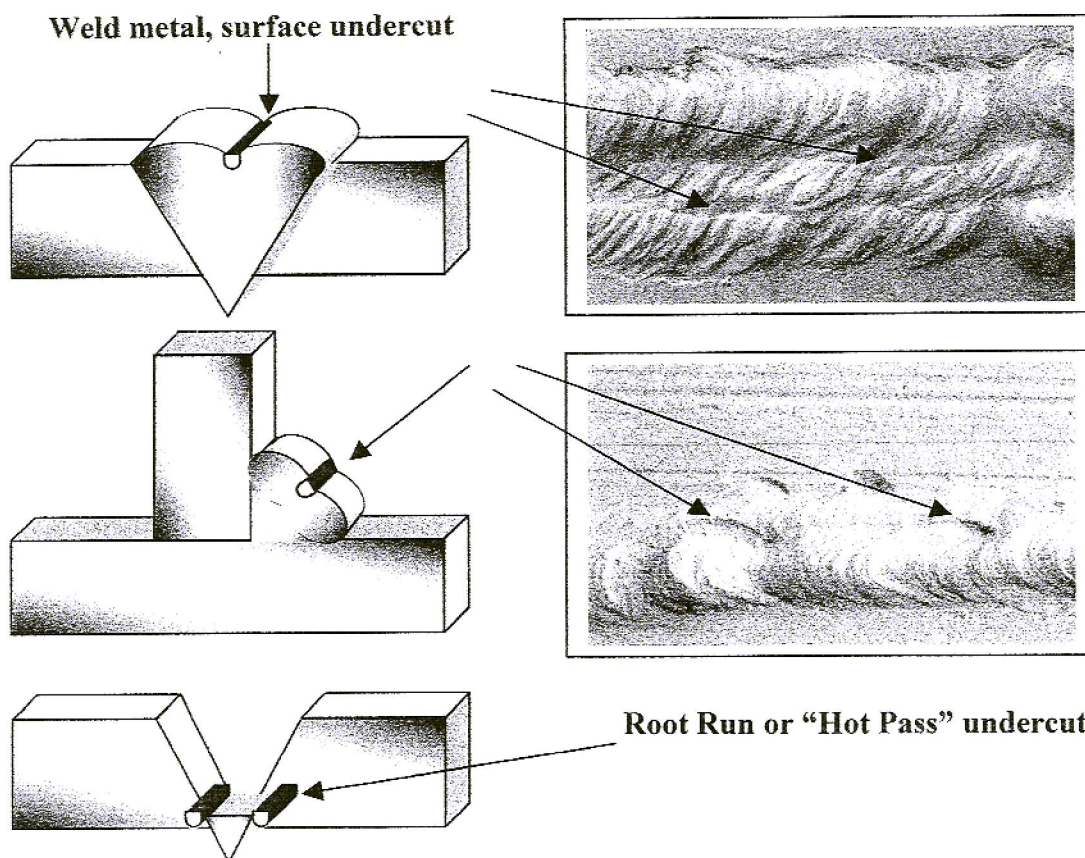
An **irregular bead width** is a surface imperfection, which is often referenced in application standards as. *"The weld bead should be regular along its length"*



Undercut

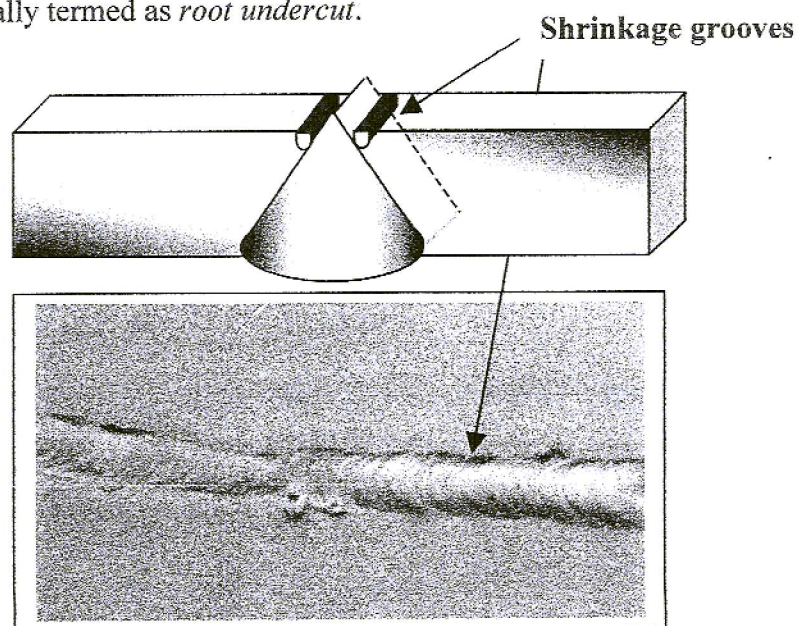
Undercut can be defined as a depression at the toe of a weld in a previous deposited weld or base metal caused by welding. Undercut is principally caused by an incorrect welding technique, including too high a welding current, too slow a travel speed in conjunction with the welding position i.e. 2F and PB. It is often found in the top toe of fillet welds when attempting to produce a leg length >9mm in one run. Undercut can be considered a serious imperfection, particularly if sharp as again it causes high stress concentrations. It is gauged in its severity by **length, depth and sharpness**.





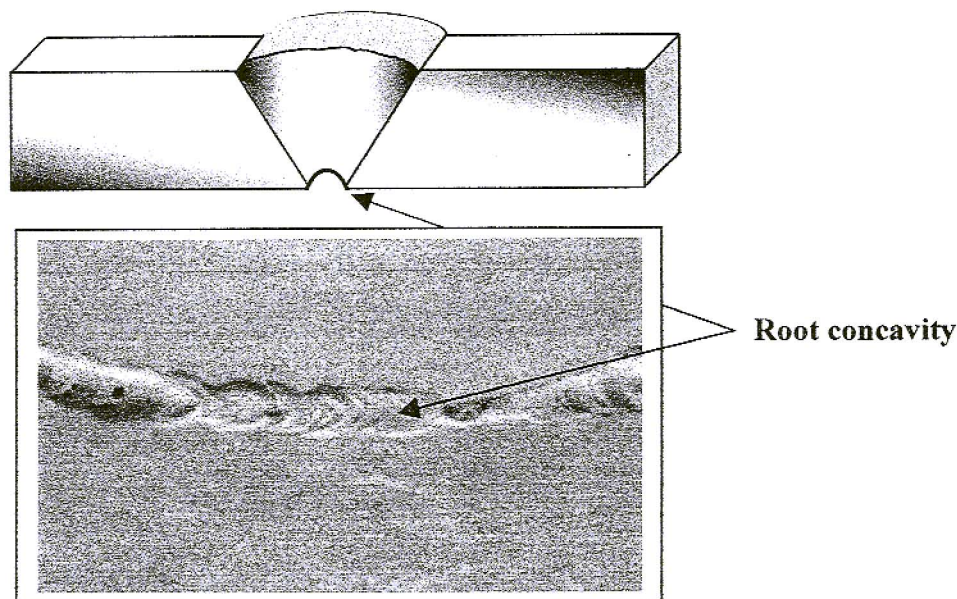
Shrinkage grooves

Shrinkage grooves may occur in the root area and are caused by contractional forces in the weld metal pulling on the hot plastic base metal in the root area. This condition is often colloquially termed as *root undercut*.



Root concavity. (Suck back)

This may be caused when using too high a gas backing pressure in purging. It may also be produced when welding with too large a root gap and depositing too thin a root bead, or too large a hot pass which may pull back the root bead through contractional stresses.



Excess root penetration

May be caused by using too high a welding current, and/or, slow travel speed, a large root gap, and/or a small root face. It is often accompanied by burn through, or a local collapse of the weld puddle causing a hole in the weld root bead. **Penetration is only excessive** when it **exceeds the allowable limit**, as laid down in the applied application standard.

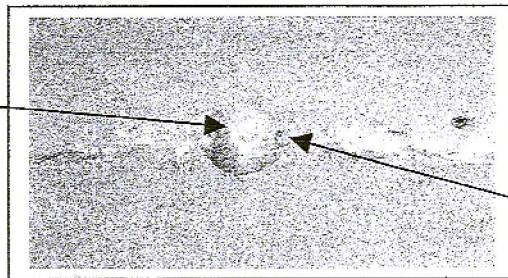
Root oxidation

Root oxidation may take place when welding re-active metals such as stainless steels with contaminated, or inadequate purging gas flow.

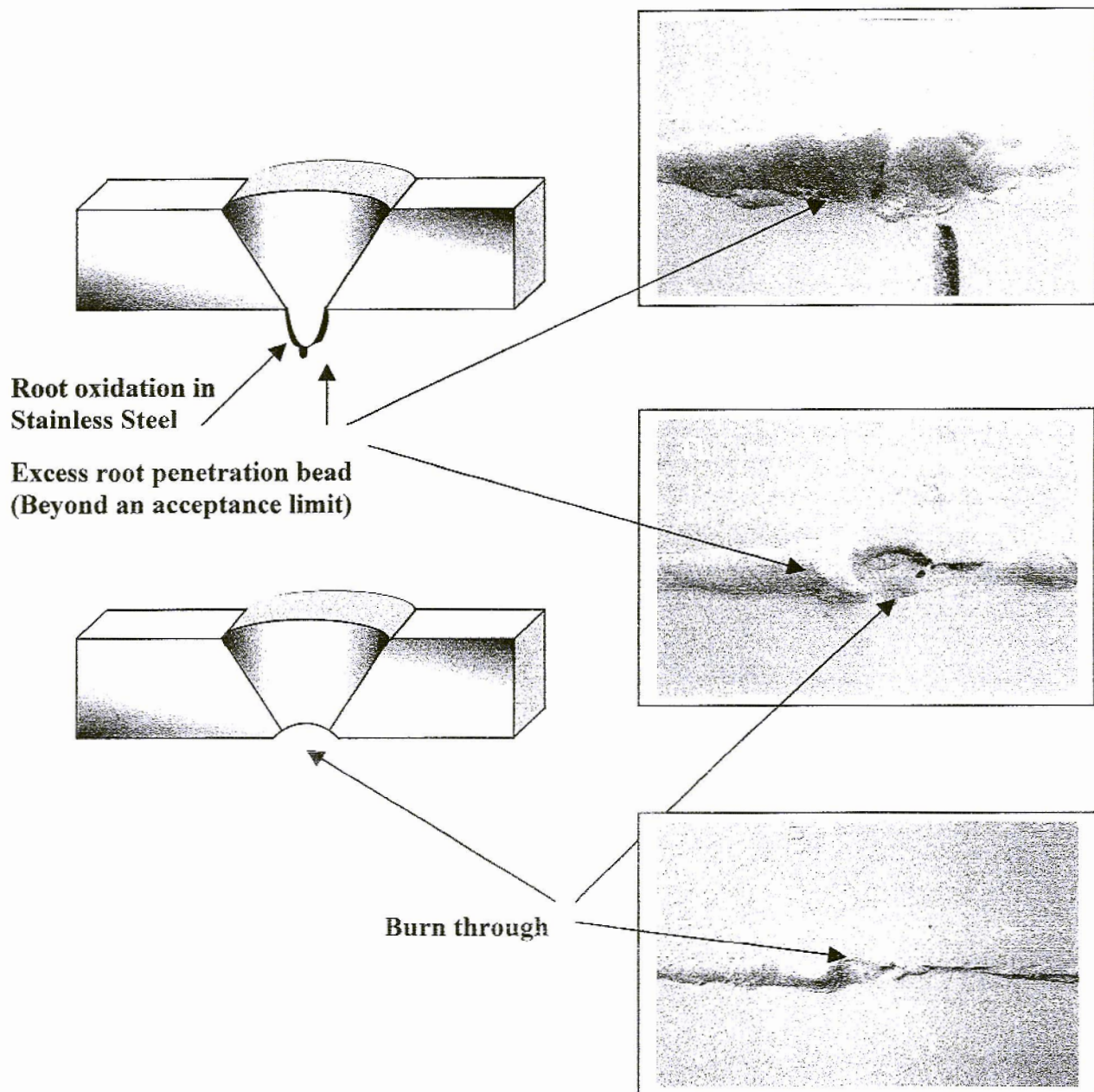
Incompletely fused Tack Welds

It is often a procedural requirement for tack welds to be *feathered* (Lightly ground and blended) prior to welding. This requirement is mainly dependent upon the class of work. Feathering should enable the tack welds to be more easily blended and any failure to achieve this correctly may result in a degree of **lack of root fusion/penetration** occurring in the weld root run.

*Un-feathered
root tack weld*



Adjacent weld area showing
a lack of root fusion and/or
root penetration
(See also page 3.6)



A Burn Through may be caused by a severely excessive root penetration bead followed by local collapse of the weld root in the effected area.

It may be generally caused by a combination of the following factors:

- a) > welding current
- b) > root gap
- c) < root face
- d) < speed of travel

Its occurrence is also very dependent upon the *welding position* and the *effect of gravity*.

To summarise, surface/profile welding imperfections are as follows:

- 1) Incompletely filled groove/lack of fusion
- 2) Spatter
- 3) Arc strikes. (Stray arcs)
- 4) Incomplete root penetration
- 5) Lack of root fusion
- 6) Bulbous, or irregular contour
- 7) Poor toe blend
- 8) Irregular bead width
- 9) Undercut. (Weld and Base metal)
- 10) Root concavity. Root shrinkage grooves
- 11) Excess penetration. Burn through
(Comparatively measured as **radiographic density** in some line pipe standards)
- 12) Root oxidation

Surface and profile imperfections are mainly caused by a **lack of applied welding skill**.

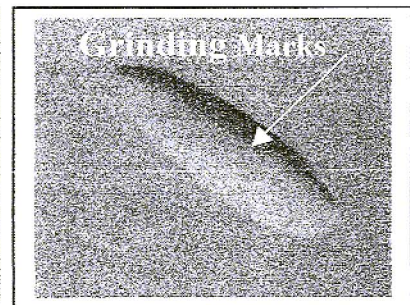
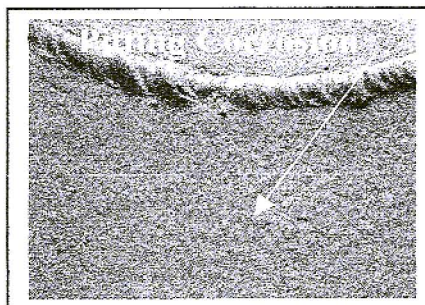
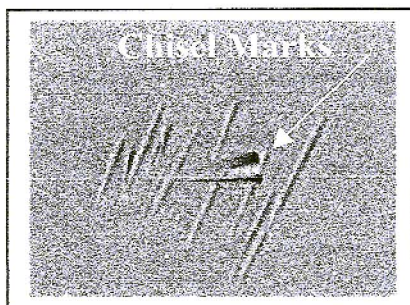
6) Mechanical/Surface damage

Mechanical/Surface damage

This can be defined as any material surface damage caused during the manufacturing or handling process, or in-service conditions. This can include damage caused by:

- | | |
|---|--|
| 1) Grinding | 2) Chipping |
| 3) Hammering | 4) Removal of welded attachments by hammering |
| 5) Chiselling | 6) Using needle guns to compress weld capping runs |
| 7) Corrosion <i>(Not caused through welding, but is considered during inspection)</i> | |

As with the stray arcing, the above imperfections can be detrimental as they reduce the through thickness dimension of the plate in that area. They can cause local stress concentrations and should be repaired prior to completing the job.

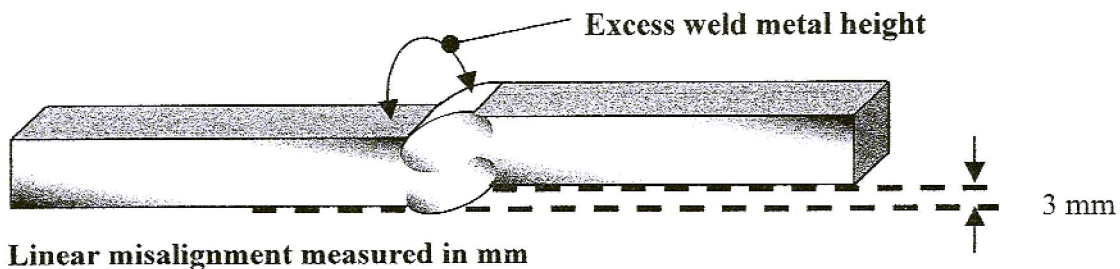


7) Misalignment

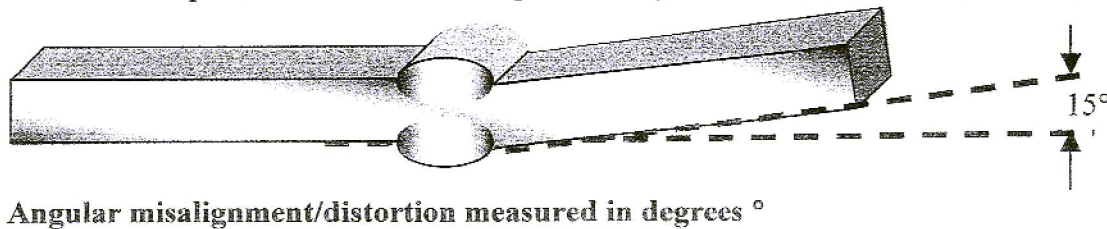
There are 2 main forms of misalignment in plate materials, which are termed:

- 1) Linear misalignment
- 2) Angular misalignment/distortion

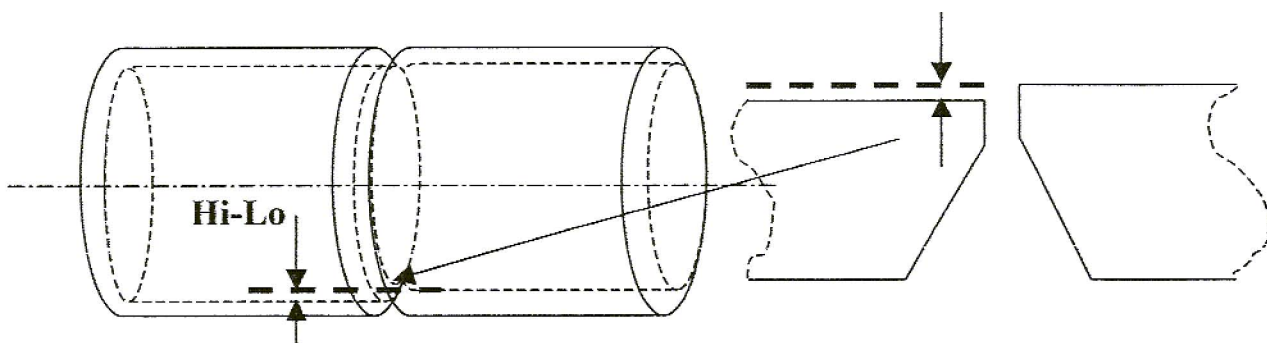
Linear misalignment: can be controlled by the correct use/control of the weld set up technique i.e. tacking, bridging, clamping etc. **Excess weld metal height and the root penetration bead are always measured from the lowest plate to the highest point of the weld metal, as shown below.**



Angular misalignment/distortion: may be controlled by the correct application of distortion control techniques, i.e. balanced welding, offsetting, or use of jigs, fixtures, clamps, etc.



Hi-Lo is a term that is generally used to describe the unevenness across the root faces between pipes found during set up and prior to welding. This unevenness is often caused by an un-matching and/or irregular wall thickness, or between pipes having any degree of ovality.



Summary of Welding Imperfections:

Group	Type	Causes/Location
1) Cracks	Centreline	Weld Metal
	H ₂	Weld Metal & HAZ
	Lamellar Tears	Base metal
2) Porosity/Cavities	Porosity	Damp electrodes
	Gas pore $\leq 1.5\text{mm } \varnothing$	Un-cleaned plates/pipes
	Blow hole $> 1.5\text{mm } \varnothing$	Loss of gas shield
	Shrinkage cavity	Weld metal (high d:w)
3) Solid Inclusions	Slag MMA/SAW	Poor Inter-run cleaning
	Silica TIG/MAG (Fe steels)	Undercut in hot pass. Arc blow
	Tungsten TIG	Dipping tungsten in weld pool
	Copper (MIG/MAG)	Dipping tip in weld pool
4) Lack of Fusion	Lack of side wall fusion (Can be surface breaking)	Arc Blow
	Lack of root fusion	Incorrect welding technique
	Cold lap/overlap	Non feathering of tack welds
5) Surface & Profile	Poor toe blend	Positional welding technique
	Arc Strikes	Incorrect welding technique
	Incomplete penetration	Poor welding technique
	Incompletely filled groove	< Root gap/Amps. > Root face
	Spatter	Incorrect welding technique
	Bulbous contour	Damp consumables
	Undercut: Surface and internal	Incorrect welding technique
	Shrinkage groove (Root)	Too high an amperage
	Root concavity	Poor welding technique
	Excess Penetration	Contractional stress
	Burn through	Too high gas pressure
	Crater Pipes (Mainly TIG)	Too large root gap/amps
6) Mechanical damage	Hammer/Grinding marks etc.	Too small a root face
7) Misalignment	Angular Misalignment (°)	Incorrect current slope-out
	Linear Misalignment (mm)	Poor workmanship
	Hi-Lo (mm)	Poor fit-up. Distortion
		Poor fit-up
		Irregular pipe wall or ovality

Notes:

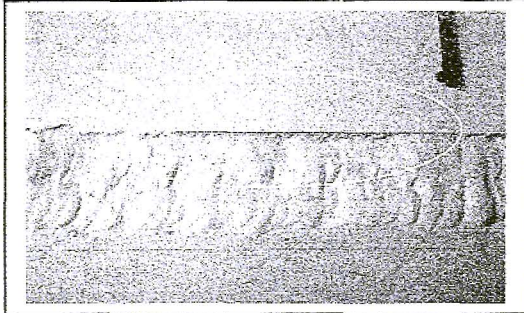
The causes given in the above table should not be considered as the only possible causes of the imperfection given, but as an example of a probable cause.

Good working practices and correct welder training will minimise the occurrence of unacceptable welding imperfections. (*Welding defects*)

WIS 5 Section 3 Exercise:

Observe the following photographs and identify any *Welding Imperfections*:
(As indicated within the ovals)

1) Plate. Butt Weld Face



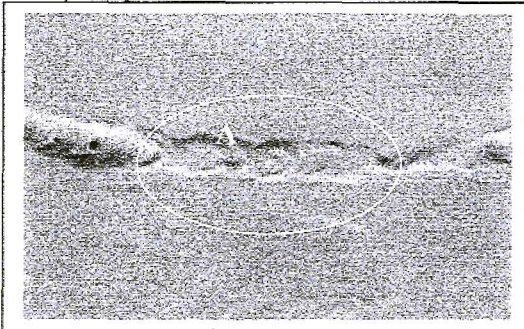
A

2) Plate. Butt Weld Root



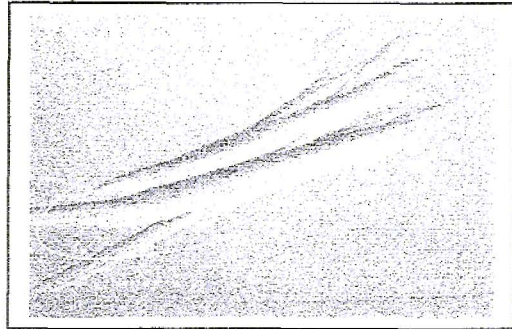
A

3) Pipe. Butt Weld Root



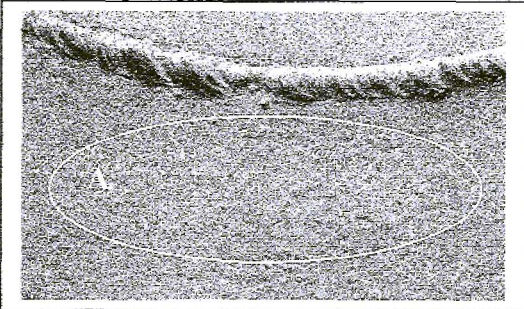
A

4) Plate. Butt Weld Face



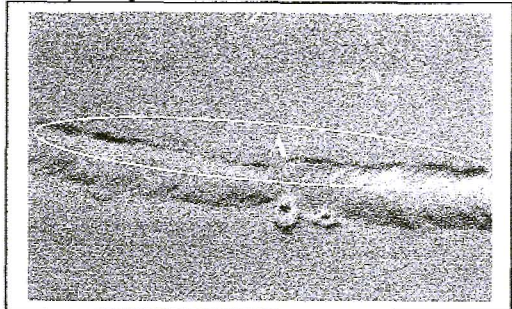
A

5) Pipe. Butt Weld Root



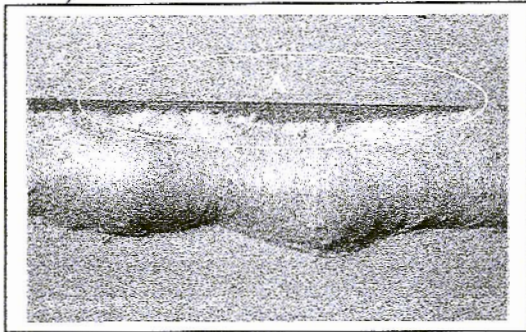
A

6) Pipe. Butt Weld Root



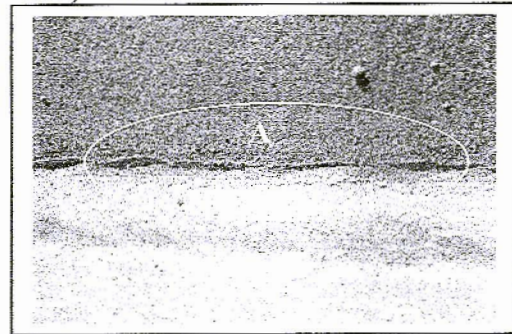
A

7) Plate. Butt Weld Face



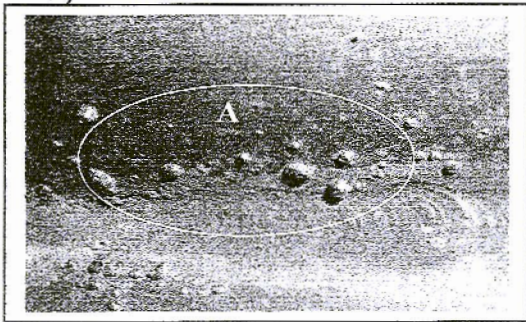
A

8) Plate. Fillet Weld Face



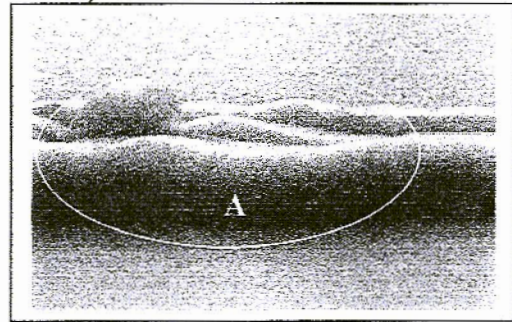
A

9) Plate. Fillet Weld Face



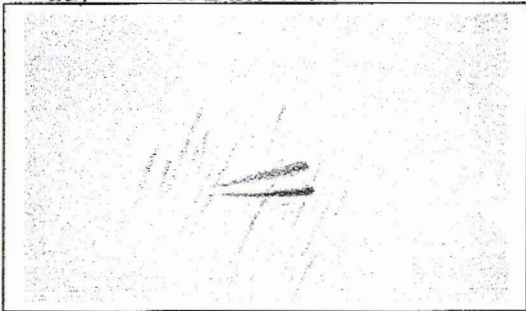
A

10) Plate. Butt Weld Face



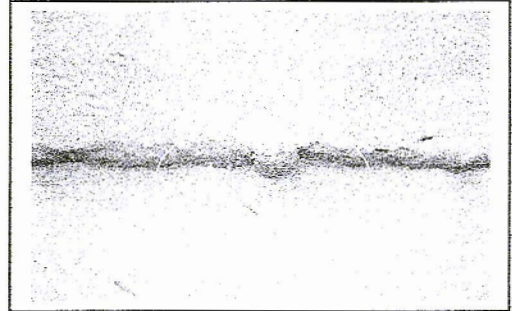
A

11) Plate. Butt Weld Face



A

12) Plate. Butt Weld Root



A

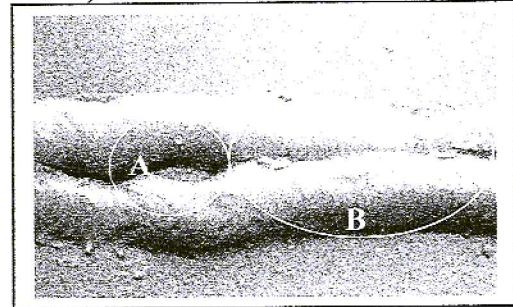
13) Plate. Butt Weld Root



A

B

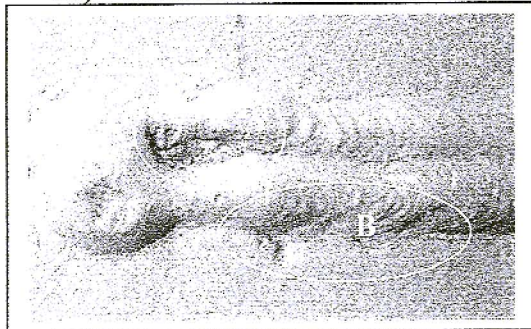
14) Plate. Butt Weld Face



A

B

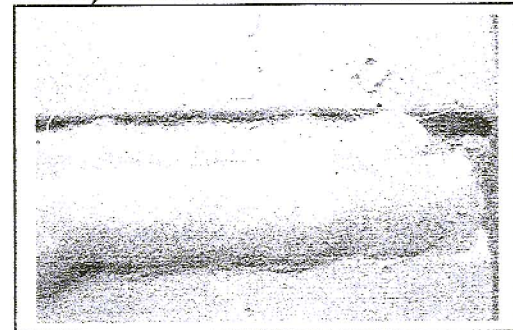
15) Plate. Butt Weld Face



A

B

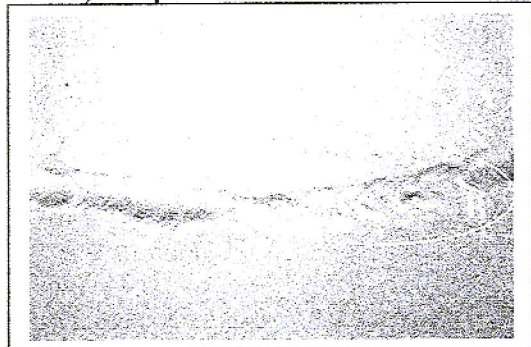
16) Plate. Butt Weld Face



A

B

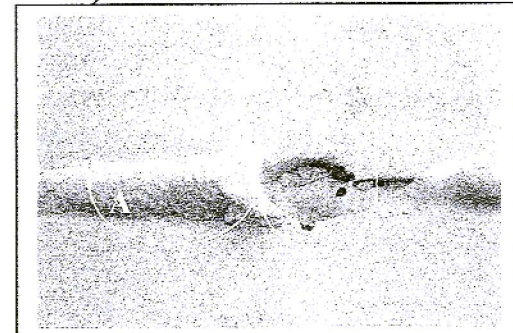
17) Pipe. Butt Weld Root



A

B

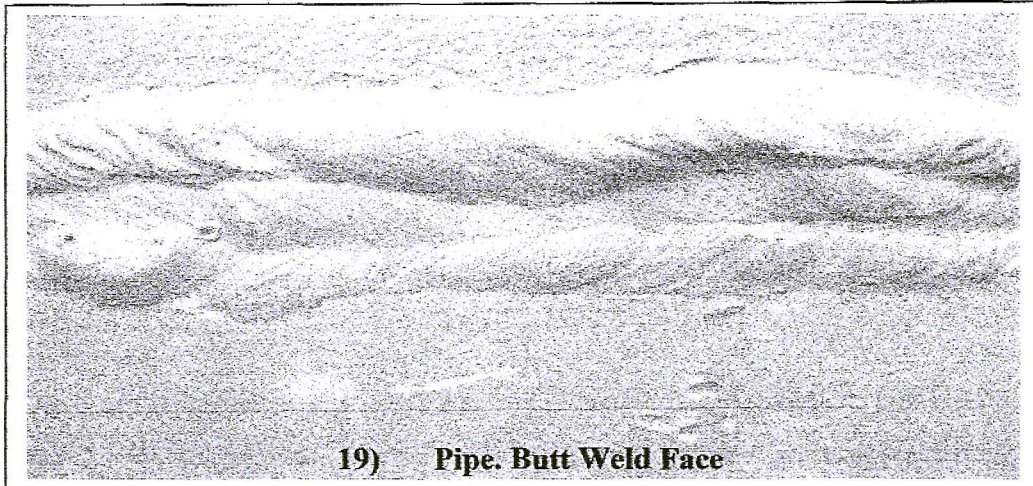
18) Plate. Butt Weld Root



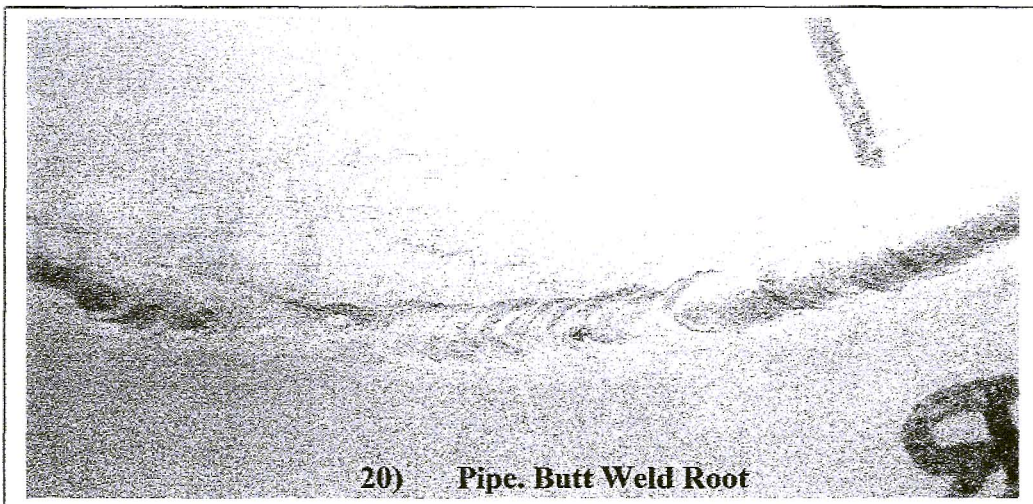
A

B

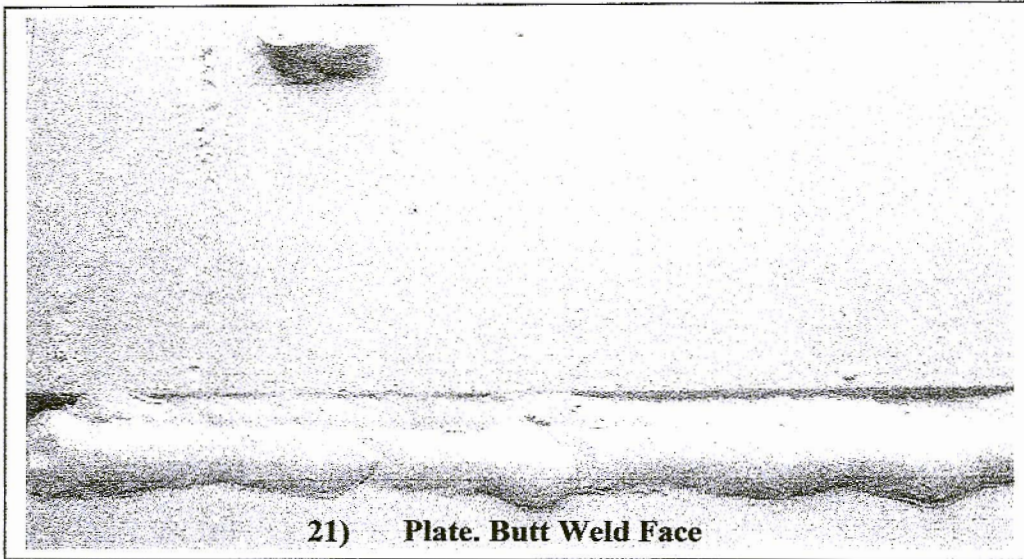
Record all welding imperfections *that can be observed* in photographs 19-24:



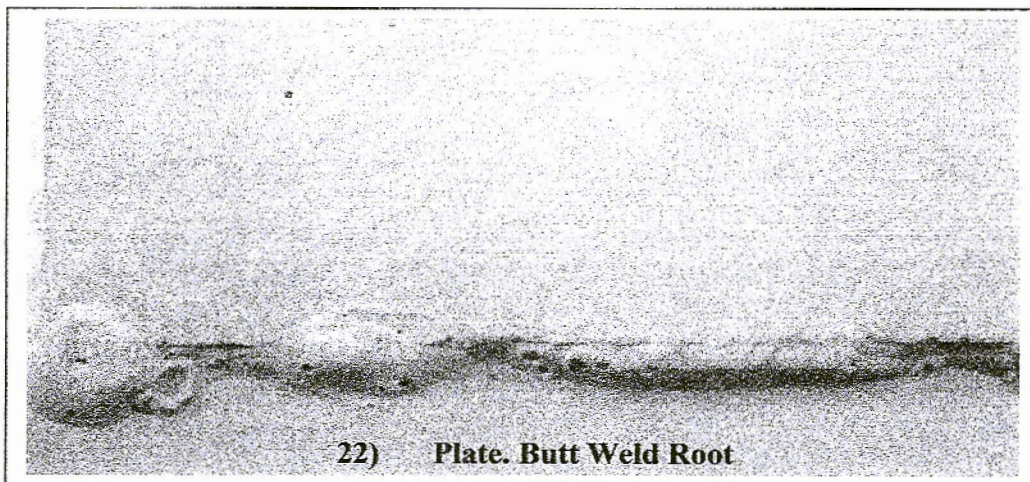
19) Pipe. Butt Weld Face



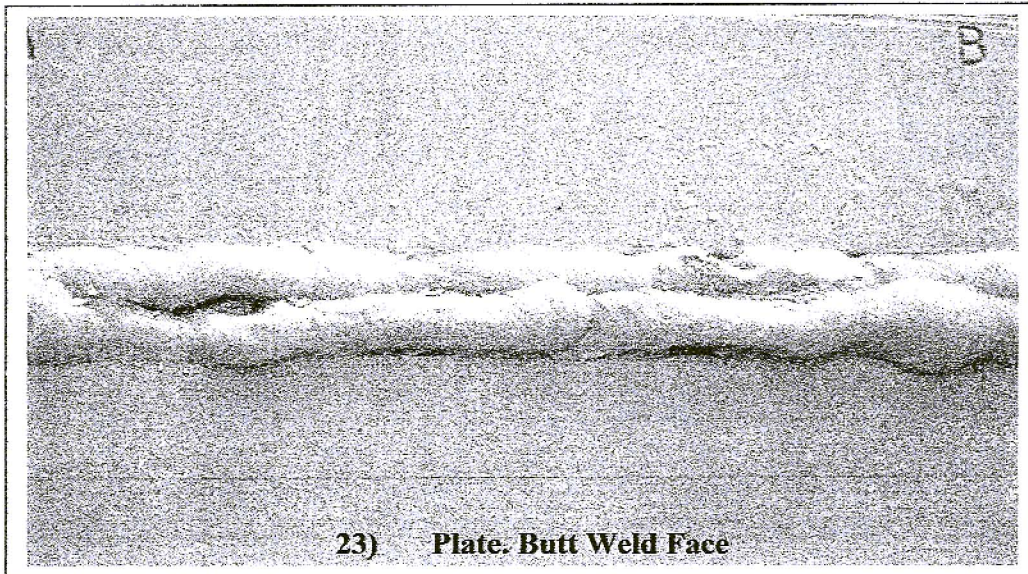
20) Pipe. Butt Weld Root

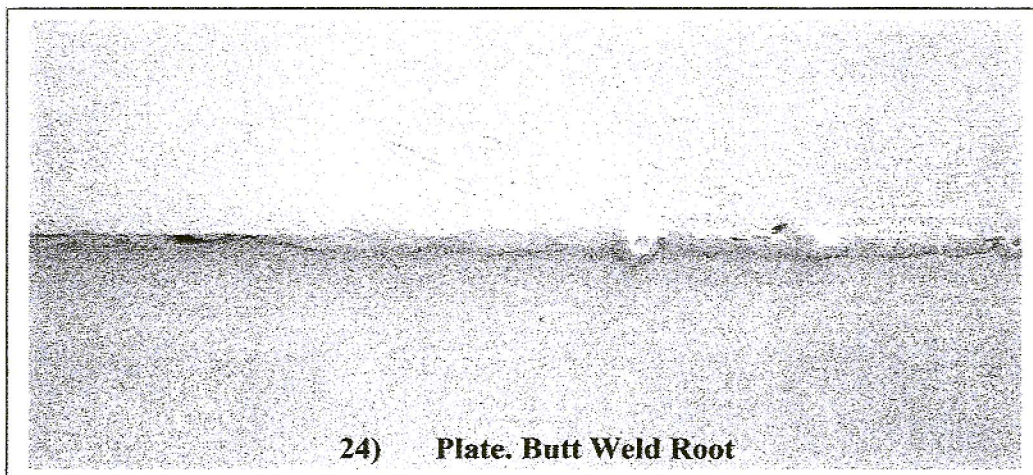


21) Plate. Butt Weld Face



22) Plate. Butt Weld Root





WIS 5 Welding Inspection

Section 04

Mechanical Testing

Destructive/Mechanical Testing:

Destructive and/or mechanical tests are generally carried out to ensure that the required levels of certain mechanical properties have been achieved. When metals have been welded, the mechanical properties of the plates may have changed in the HAZ due to the thermal effects of the welding process. It is also necessary to establish that the weld metal itself reaches the minimum specified values.

The mechanical properties or material characteristics most commonly evaluated include:

- | | | |
|---|------------------|---|
| X | Hardness | The ability of a material to resist indentation |
| X | Toughness | The ability of a material to resist fracture under impact loads |
| X | Strength | The ability of a material to resist a force. (Normally tension) |
| X | Ductility | The ability of a material to plastically deform under tension |

→ assess resistant
to brittle fracture
to define
Brittle fracture

To carry out these evaluations we require specific tests. There are a number of mechanical tests available to test for these specific mechanical properties the most common of which are:

- | | | |
|----|---|--|
| 1) | Hardness testing. (Vickers/Brinell/Rockwell) | } Used to <u>measure</u>
Quantity XXX |
| 2) | Toughness testing. (Charpy V/Izod/CTOD) | |
| 3) | Tensile testing. (Transverse/All weld metal) | |

Tests 1 – 3 have **units** and are termed **quantitative** tests

We use other tests to evaluate the quality of welds

- | | | |
|----|---------------------------------------|--|
| 4) | Macro testing | } Used to <u>assess</u>
Quality XXX |
| 5) | Bend testing. (Side/Face/Root) | |
| 6) | Fillet weld fracture testing | |
| 7) | Butt weld Nick-break testing | |

Tests 4 – 7 have **no units** and are termed **qualitative** tests

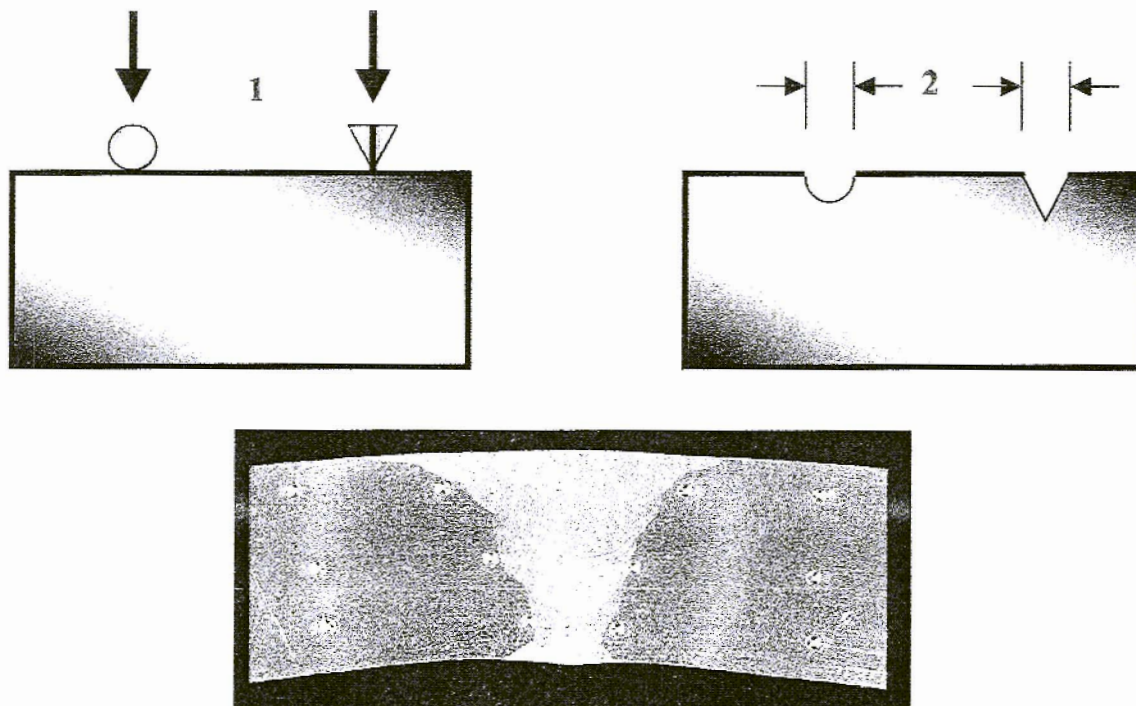
1) Hardness tests. (Used to measure the level of hardness across the weld)

Types of hardness test include:

- | | | |
|---|-------------------------------|----------------------------------|
| x | a) Rockwell scale | (Diamond or steel ball) |
| x | b) Vickers pyramid. HV | (Diamond) |
| x | c) Brinell. BHN | (5 or 10 mm diameter steel ball) |
| | d) Shore Schlerescope | (Measures resilience) |

Most hardness tests are carried out by (1) impressing a ball, or a diamond into the surface of a material under a fixed load, (2) then measuring the resultant indentation and comparing it to a scale of units (BHN/HV etc.) relevant to that type of test. Hardness surveys are generally carried out across the weld as shown below. In some applications it may also be required to take hardness readings at the weld junction/fusion zone.

A **Shore Schlerescope** measures resilience by dropping a weight from a height onto the surface then measuring the height of the rebound. The higher the rebound the higher is the resilience of the material. As resilience in materials may be directly correlated to hardness then the hardness may be read in any or all sets of units. Early equipment was cumbersome, but still far more portable compared to other hardness testing methods available. Equipment is now available which works on the resilience principle and is the size of a ballpoint pen. This form of equipment may be used by the welding inspector to *indicate* hardness values on site, and is scaled in all of the common hardness scales.



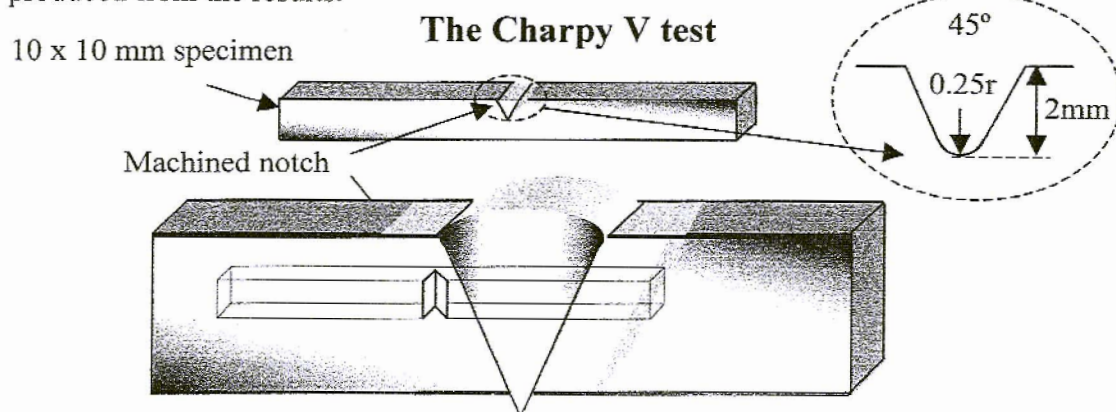
2) Toughness tests. (Used to **measure** resistance to fracture under impact loading)

XXX

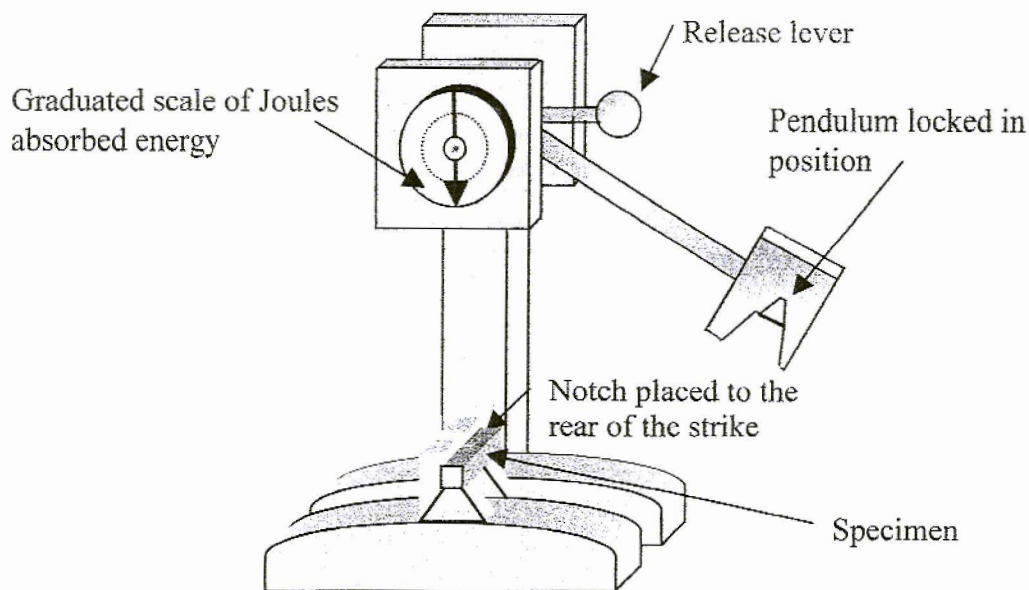
Types of toughness test include:

- a) **Charpy V.** (Joules) Specimen held horizontally in test machine, notch to the rear.
- b) **Izod.** (Ft.lbs) Specimen held vertically in test machine, notch to the front.
- c) **CTOD or Crack Tip Opening Displacement testing.** (mm)

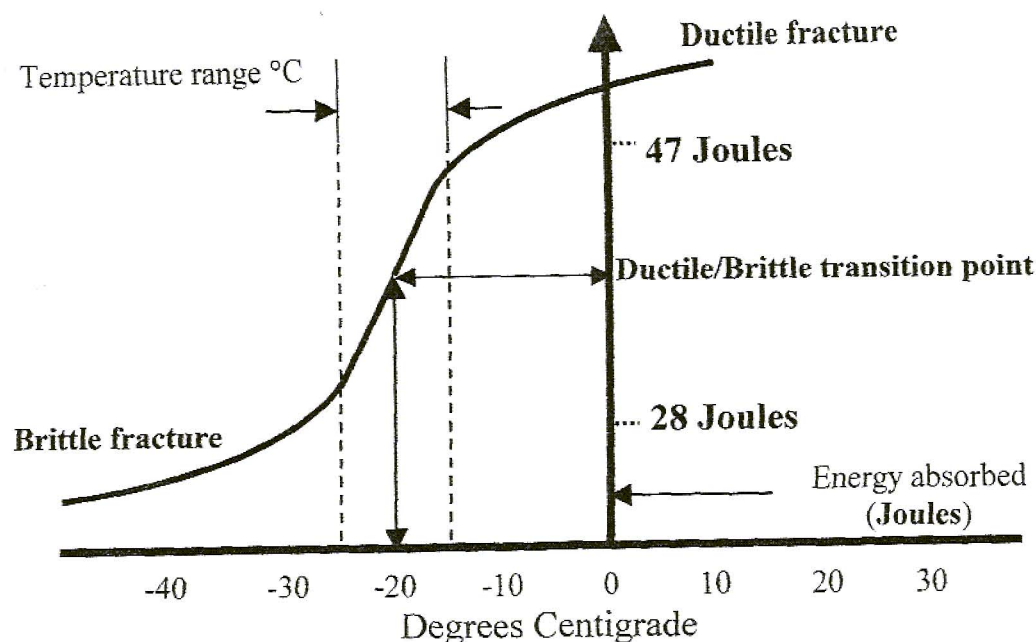
There are many factors that affect the toughness of the weldment and weld metal. One of the important effects is that of testing temperature. In the Charpy V and Izod test the toughness is assessed by the amount of impact energy absorbed by a small specimen of 10 mm² during fracture by a swinging hammer. A temperature transition curve can be produced from the results.



The **notch** may be machined either in the Weld metal, Fusion zone or HAZ depending on which area/zone is to be evaluated during the test. The standard notch is 2mm deep, 0.25 mm root radius, and included angle 45 ° though other shapes of notches exist i.e. "U" with all relevant dimensions given in the standard. A smaller version of this test is also available.



A Ductile/Brittle transition curve for a typical C/Mn Structural Steel



The transition temperature of welded steels can be affected by many factors including:

XX a) Alloying (Chemical composition)

The curve can *effectively* be moved to the left by additions of **manganese** of up to 1.6 % **maximum** as this has a positive effect on improving the toughness of plain ferritic steels at cryogenic temperatures. **Nickel** also has a very positive effect on low temperature toughness of steels, however nickel is a very **expensive** metallic element and is only used where low temperatures are severe. Steels containing 5-9% nickel have excellent low temperature toughness with fully austenitic stainless steels having measurable toughness down to -270°C .

XX b) Heat input

The above curve can *effectively* be moved to the right by using a **high heat input** during the welding cycle, where **Time** at **Temperatures** spent above the **Critical Temperatures** of the steel allows grains to grow and fuse together to form larger grains. (**Grain Growth**) Energy required in fracturing a large or a coarser grained steel is comparatively lower than **finer grained steel**, hence the need to control heat input and/or limit **maximum inter-pass temperatures**. A fine grain structure will effectively move the curve to the left i.e. **Increase** the relative **toughness** values of a steel.

c) Chemical cleaning

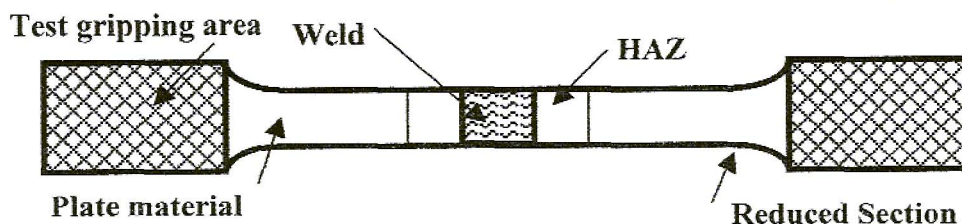
The cleanliness of the weld metal will also greatly affect its level of toughness. Welding fluxes containing high amounts of **basic compounds** give much higher **toughness & strength** weld metal values than welds made using lower amounts of these compounds.

3) Tensile Tests. (Used to measure tensile strength and ductility)

Types of tensile test:

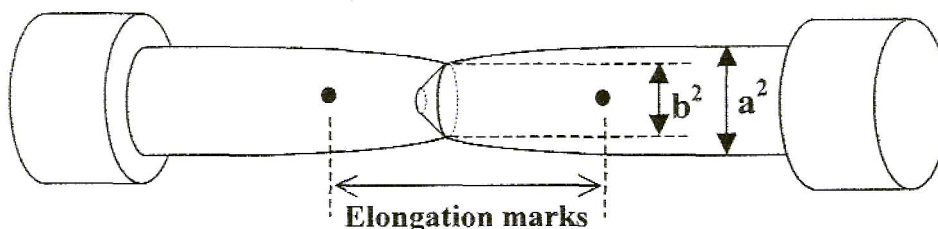
- Transverse reduced section**
Used to measure the tensile strength of the weldment.
- Longitudinal all weld metal tensile test**
Used to measure tensile strength, yield point and E% of deposited weld metal.

A transverse tensile test specimen prior to testing



In a transverse test failure is generally expected in the base material, though failure in the weld or HAZ is not reason to fail the test if minimum specified stress has been met. An All weld metal tensile test is carried out to determine the deposited weld metal strength in N/mm^2 and weld the metal ductility as elongation (E%). A weld is made in a plate and the tensile specimen is cut along the length of the weld, which would contain mainly undiluted weld metal. Prior to the test 2 marks are made 50 mm apart along the length of the specimen. As the test is carried out the yield load and fracture load are recorded and documented. After fracture, the pieces are placed back together and the elongation is measured from the original gauge length with the result is given as E%

A longitudinal all weld metal tensile test specimen after testing

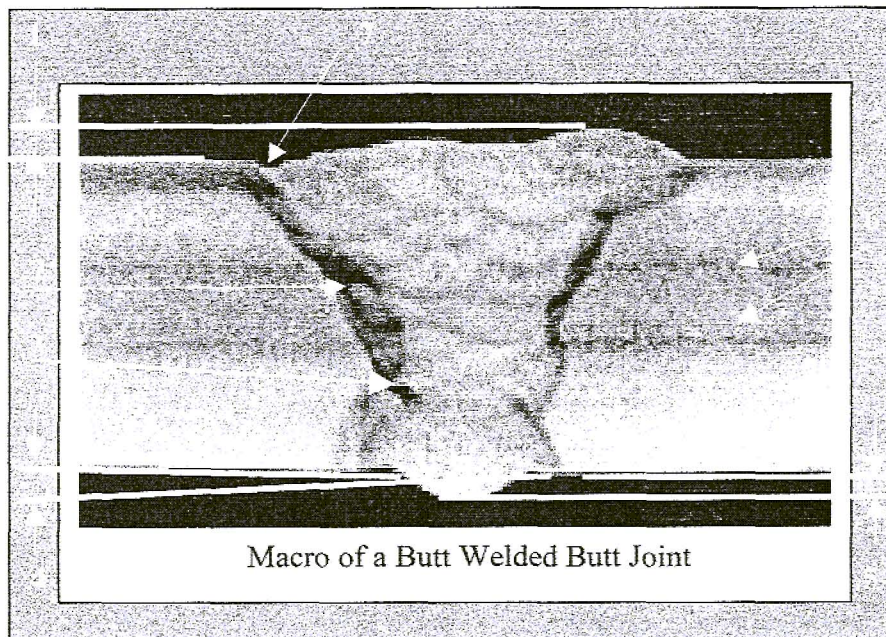


If load at yield was 8,500 N and the CSA Cross Sectional Area was $25 mm^2$ the resultant calculation of Force/CSA the yield stress (R_e) would be $8,500N/25mm^2 = 340N/mm^2$. The calculation of the tensile stress of the metal can be similarly calculated on fracture. E% If the original gauge length was 50mm and the final length on fracture is 61mm this indicates a linear extension of 11mm on the original gauge length $\therefore$ If $100\%/50mm = 2$ $\therefore 2 \times 11mm = 22\%E$. This is typical value for and C/Mn steel weld metal. Any addition of carbon to steels will reduce its ductility. Occasionally, where insufficient material is available a short transverse test indicating a % reduction in area may be used and is calculated as STRA (Short Transverse Reduction in Area) i.e. $a) mm^2 - b) mm^2$. This method is often used when assessing a steels susceptibility to Lamellar Tearing.

4) **Macro examination tests.** (Used to assess the internal quality of the weld)

A macro specimen is normally cut from a **stop/start** position in the root, or hot pass of a welder approval test. The start/stop position is marked out during a welder approval test by the welding inspector. Once cut, the specimen is polished using progressively finer grit papers and polishing at 90° to previous polishing direction, until all the scratches caused by the previous polishing direction have been removed. It is then etched in an acid solution which is normally 5 -10% Nitric acid in alcohol (plain carbon steels). Care must be taken not to under-etch or over-etch as this could mask the elements that can be observed on a correctly etched specimen. After etching for the correct time the specimen is then washed in acetone and water, thoroughly dried, and may also be preserved.

A visual examination should be carried out at all stages of production to observe any imperfections that are visible. Finally, a report is then produced on the visual findings then compared and assessed to the levels of acceptance in the application standard. Macro samples may be sprayed with clear lacquer after inspection, for storage purposes.



Macro Assessment Table

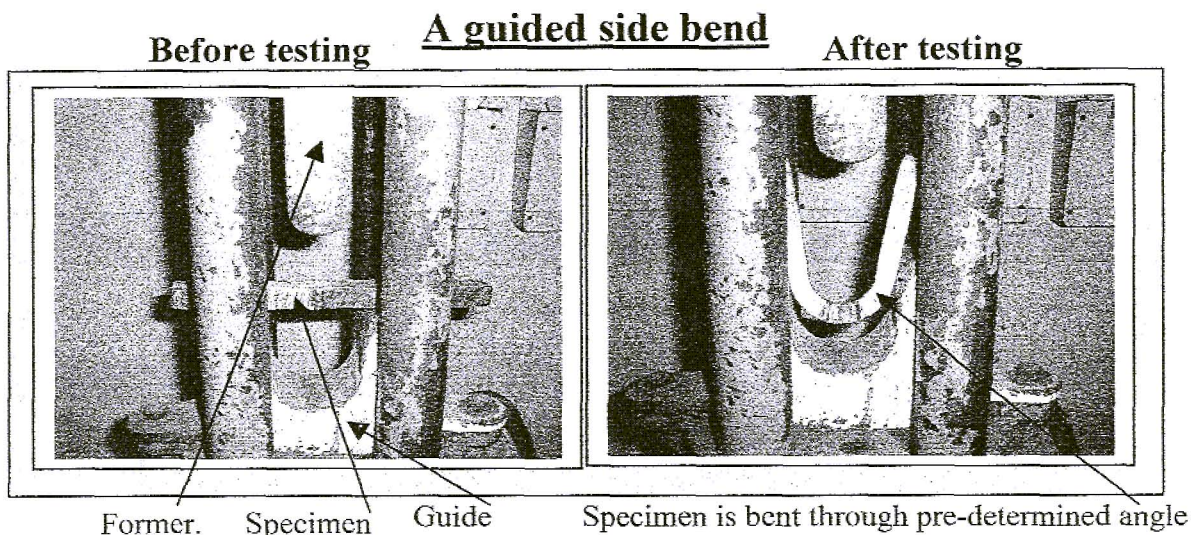
- | | |
|---------------------------------------|--------------------------------------|
| 1) Excess weld metal height | 2) Slag with lack of sidewall fusion |
| 3) Slag with lack of inter-run fusion | 4) Angular misalignment |
| 5) Root penetration bead height | 6) Segregation bands |
| 7) Lack of sidewall fusion/Undercut? | |

A Macrograph is a qualitative method of mechanical testing/examination as it is only weld quality that is being observed in this test.

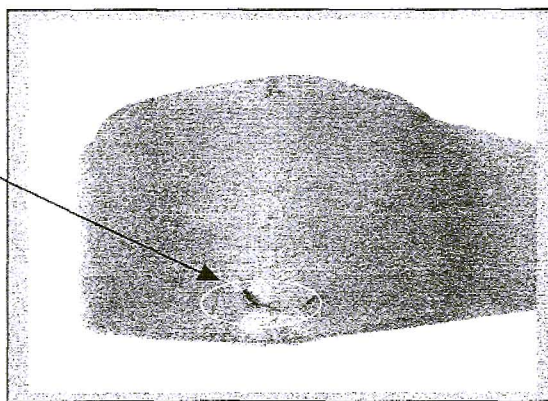
5) Bend tests. (Used to assess weld ductility & fusion in the area under stress)

The former is moved through a guide (guided bend test), or rollers, and the specimen is bent to the desired angle. Types of guided bend test include:

- a) Face bends b) Root bends c) Side bends d) Longitudinal bends



Lack of sidewall fusion



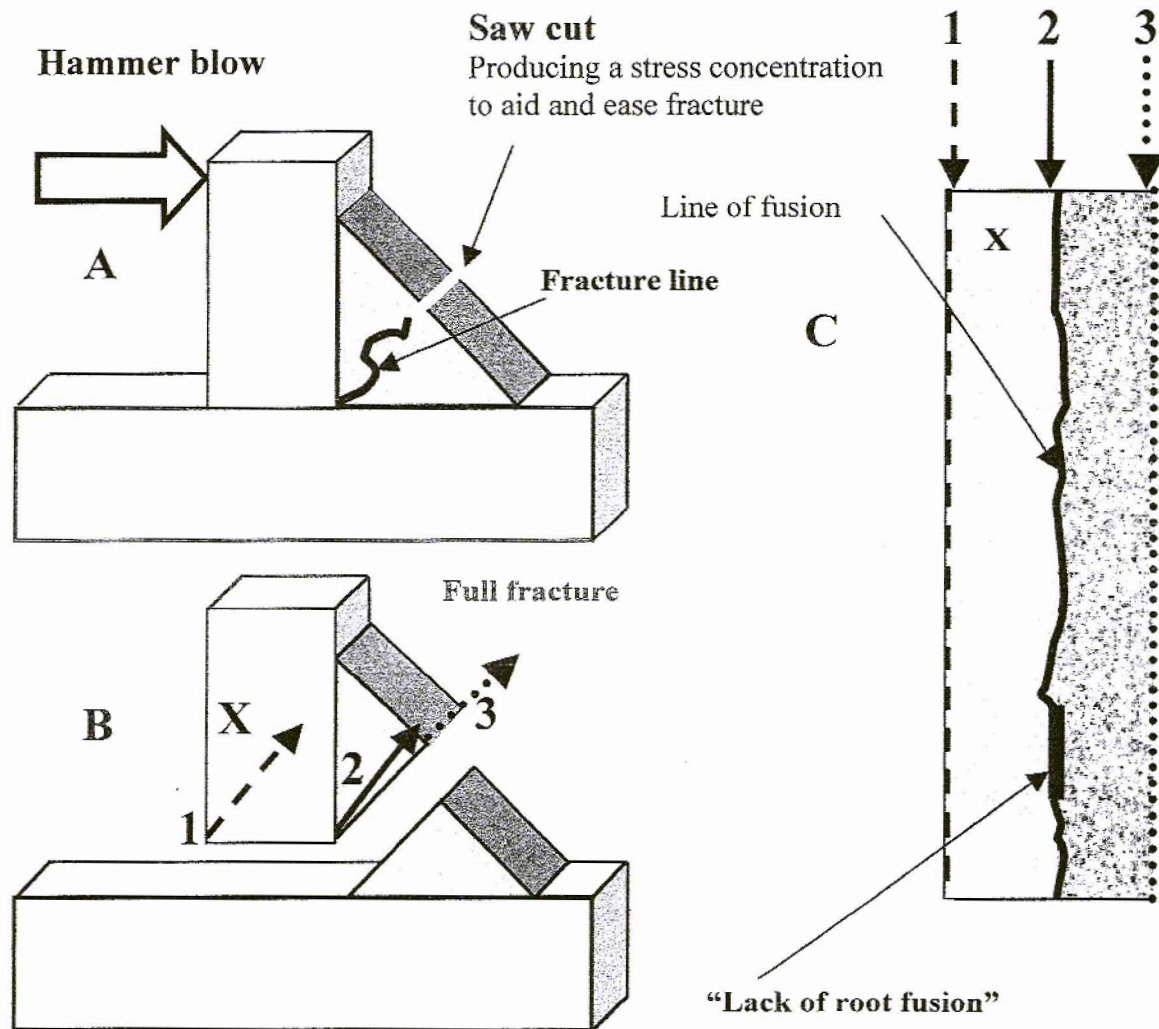
Any areas containing a lack of fusion become visible as the stress is applied. This may also result in tearing of the specimen, caused by local stress concentration, as shown above. Bend tests are carried out for welder approval tests, and procedure approval to establish good sidewall, root, or weld face/root fusion. Inspection of the test face is made after the bending to check the integrity of the area under test. Face, root, side and longitudinal tests may be carried out in thickness below 12mm. For materials greater than 12mm thickness, a slice of 10-12mm is normally cut out along the length and the material is side bend tested.

Bend testing is a qualitative method of mechanical testing/examination as it is only the weld quality that is being observed. (Although ductility is very often observed, it cannot be measured in this test.)

6) Fillet weld fracture tests. (Used to assess root fusion in fillet welds)

A fillet weld fracture test is normally only carried out during a welder approval test. The specimen is normally cut by hacksaw through the weld face to a depth (usually 1–2 mm) stated in the standard. It is then held in a vice and fractured with a hammer blow from the rear. After fracture has been made both surfaces are then carefully inspected for imperfections.

Finally the vertical plate **X** is moved through 90° and the line of root fusion is observed for continuity. Any straight line would indicate a lack of root fusion. In most standards this is sufficient to fail the welder.

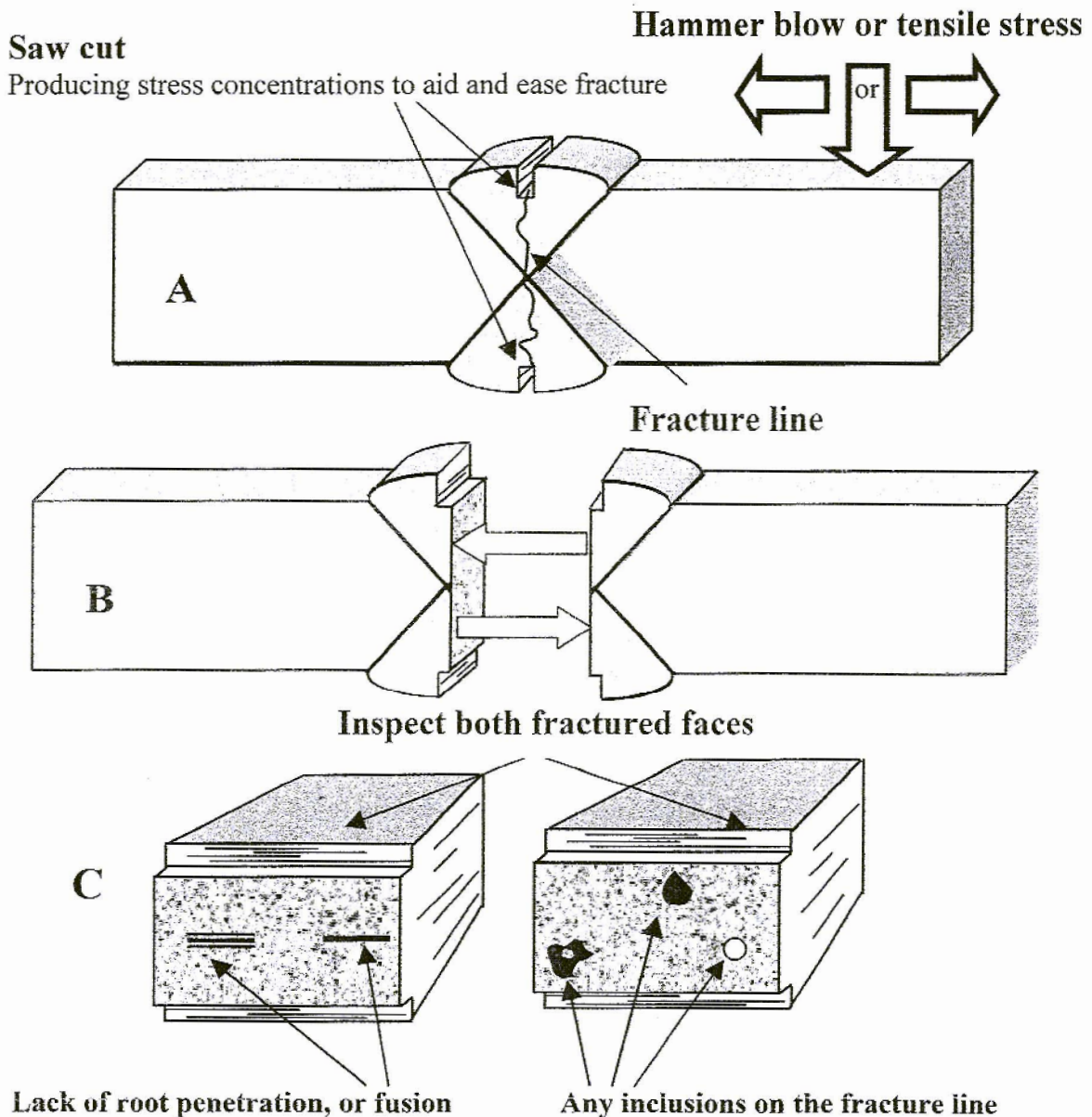


After inspection of both fractured surfaces for imperfections, turn fracture piece **X** through 90° vertically and inspect the line of root fusion. (**Line 2**)

A Fillet weld fracture test is a qualitative method of mechanical testing/examination as it is only the weld quality that is being observed in this test.

7) **Nick-break tests.** (Used to assess root fusion in double butt welds)

Used to assess root penetration and fusion in double-sided butt welds, and the internal faces of single sided butt welds. A Nick-break test is normally carried out during a welder approval test. The specimen is normally cut by hacksaw through the weld faces to a depth stated in the standard. It may then be held in a vice and fractured with a hammer blow from above, or placed in tension and stressed too fracture. Once fracture has occurred both fracture faces are then turned horizontally through 90° and may then be inspected for imperfections along the fracture faces, as shown below in C.



A butt *nick-break* test is a qualitative method of mechanical testing/examination as only the weld quality is being observed.

Quantitative and Qualitative Destructive Testing XXX

Quantitative

We test weldments mechanically to establish the level of various mechanical properties
The following types of tests are typical:

- 1) **Hardness**
Vickers (VPN) Brinell (BHN) Rockwell (Scale C for steels)
- 2) **Toughness**
Charpy V (Joules) Izod (USA) (Ft.lbs) CTOD (mm)
- 3) **Tensile Strength**
Transverse reduced & radius reduced. Longitudinal all weld metal
N/mm² (PSI In the USA)

All the above tests 1 – 3 have units and are thus termed **quantitative tests**.

Ductility

Elongation E% or as % Reduction in Area

For weld metal this property is generally measured as E% during tensile testing.

XXX **Quantitative tests** are mainly used in **welding procedure approvals** tests and generally would not be used in a welder approval test.

Qualitative

We also test weldments mechanically to establish the level of quality in the weld.
In such a case we may use the following types of test:

- 4) **Macro testing**
- 5) **Bend testing.** (Face. Root. Side. & Longitudinal)
- 6) **Fillet weld fracture testing**
- 7) **Butt nick-break testing**

All the above tests 4 – 7 have no units and are thus termed **qualitative tests**.

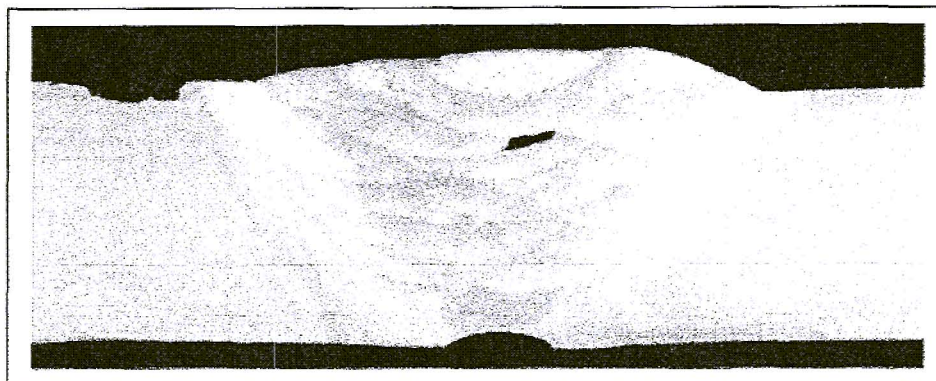
XXX **Qualitative tests** are mainly used in **welder approvals** tests though some of the qualitative tests may also be used during **welding procedural approval tests** i.e. to establish good fusion/penetration etc.

Summary of Destructive/Mechanical Testing: XXX

Name	Property or Characteristic If applicable	Qualitative or Quantitative	Units If applicable	Used <u>mainly</u> for
Rockwell scale	Hardness	Quantitative	Scale C is used for Steels	Welding Procedure tests
Vickers pyramid	Hardness	Quantitative	HV	Welding Procedure tests
Brinell	Hardness	Quantitative	BHN	Welding Procedure tests
Shore Schlerescope	Hardness <i>through</i> Resilience	Quantitative	Measures Resilience mm	<u>Assessing</u> hardness of stock materials
Charpy V	Toughness	Quantitative	Joules. <i>Energy absorbed</i>	Welding Procedure tests
Izod	Toughness	Quantitative	Ft.lbs. <i>Energy absorbed</i>	AWS Consumables Materials
CTOD	Notch Ductility Toughness	Quantitative	0.0000 mm + Detailed report	Welding Procedure tests
Transverse Reduced Tensile	Tensile Strength Ductility. STRA	Quantitative	N/mm ² or PSI + % STRA	Welding Procedure tests
All Weld Metal Tensile	Tensile Strength Ductility	Quantitative	N/mm ² or PSI Elongation %	Welding Consumable tests
Radius Reduced Transverse Tensile	Tensile Strength of weld metal	Quantitative	N/mm ² or PSI	Welding Procedure tests
Macrograph	Visual	Qualitative	N/A <i>No direct units</i>	Welder Approval or Procedure tests
Bends <i>Face Root or Side</i>	Visual. <i>Ductility may be observed</i>	Qualitative	N/A <i>No direct units</i>	Welder Approval or Procedure tests
illet Weld Fracture <i>T & Lap Joints</i>	Visual	Qualitative	N/A <i>No direct units</i>	Welder Approval or Procedure tests
Nick Break Test <i>Butt Joints</i>	Visual	Qualitative	N/A <i>No direct units</i>	Welder Approval or Procedure tests

WIS 5 Section 4 Exercises:

Study the following macrographs and report any observations in the tables given below. Use the levels of acceptance given in the Practical Inspection Section to make your assessment: Take actual sizes as measurements for this training exercise only.

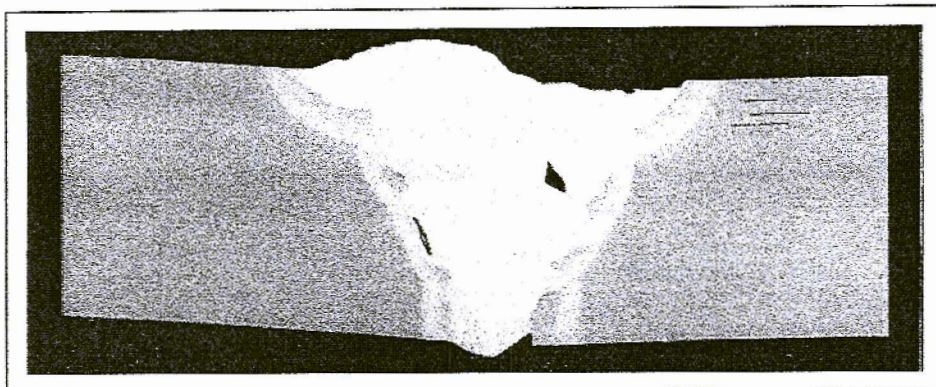


Weld Details:

Welding Process: TIG (141) Root MMA (111) Fill and Cap
Material: Stainless Steel Pipe (Argon purged)
Welding Position: 5G/PF

#	Imperfection	Size	Accept/Reject
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11	Excess Weld Metal (<i>Weld Face</i>)		
12	Excess Weld Metal (<i>Weld Root</i>)		

Comments: _____



Weld Details:

Welding Process: MMA (111) SMAW
Material: C/Mn Structural Steel Plate
Welding Position: 3G/PF

#	Imperfection	Size	Accept/Reject
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11	Excess Weld Metal (<i>Weld Face</i>)		
12	Excess Weld Metal (<i>Weld Root</i>)		

Comments: _____

Complete the table given below:

Name	Property or Characteristic If applicable	Qualitative or Quantitative	Units If applicable	Used <u>mainly</u> for
Rockwell scale	<i>Hardness</i>	<i>Quantitative</i>	<i>Scale C is used for Steels</i>	<i>Welding Procedure tests</i>
Vickers pyramid				
Brinell				
Shore Schlerescope				
Charpy V				
Izod				
CTOD				
Transverse Reduced Tensile				
All Weld Metal Tensile				
Radius Reduced Transverse Tensile				
Macrograph				
Bends Face Root or Side				
Fillet Weld Fracture T & Lap Joints				
Nick Break Test Butt Joints				

WIS 5 Welding Inspection

Section 05

Welding Procedures and Welder approvals

Welding Procedures:

What is a welding procedure?

A welding procedure is a systematic method that is used to repeatedly produce sound welds.

The use of welding as a process or method of joining materials in engineering has been long established, with new techniques and processes being developed from ongoing research and development on a regular basis. There are over 100 recognised welding or thermal joining processes of which many are either fully automated or mechanised, requiring little assistance from the welder/operator and some that require a very high level of manual input in both skill and dexterity. For each welding process there are a number of important variable parameters that may be adjusted to suit different applications, but must also be kept within specified limits to be able to produce welds of the desired level of quality for a given application. We generally term these variable parameters as **essential variables**. The most basic essential variables of any welding processes would be very much dependant on the specific nature of the process, we would need to consider the following:

- 1) The source of heat and/or method of heat application. (Where applicable)
- 2) Consumable type and method of delivery. (Where applicable)
- 3) Shielding of heat source and/or oxidation of materials. (Where applicable)
- 4) The thermal energy tolerances into the joint area. (Where applicable)
- 5) Any particular process element not covered by the above.

It is a common thought that the heat source used for most industrial welding applications is the electric arc, when in fact most welds made within industry utilise the resistance welding process. The variable parameters for the resistance welding process are very different to what would normally be expected from an arc welding procedure. For example welding procedures for the common arc and resistance spot welding of plain low carbon steels would require a setting of the following very **basic** essential variables:

Process	Basic Process Essential Variables				
MMA	Amps	AC/DC Polarity	Travel Speed	Electrode type/Ø Flux type	
SAW	Amps/ WFS	AC/DC Polarity Arc Voltage	Travel Speed	Electrode type/Ø Flux type/mesh size	Flux depth/ Electrode stick out
MIG	Amps/ WFS	Arc Voltage Inductance	Travel Speed	Electrode type/Ø	Shield gas type Gas flow rate
TIG	Amps	AC/DC Polarity	Travel Speed	Filler wire type/Ø Tungsten Type/Ø	Shield gas type Gas flow rate
Resistance Spot weld	Amps	Pressure	Time	Electrode type Contact area/shape	

It should be noted that these are the **very basic** process elements for any weld procedure.

What is the purpose of a welding procedure?

Welding procedures can be utilised for many purposes, which may include:

- a) **Economic control**
- b) **Quality control**

Economic control

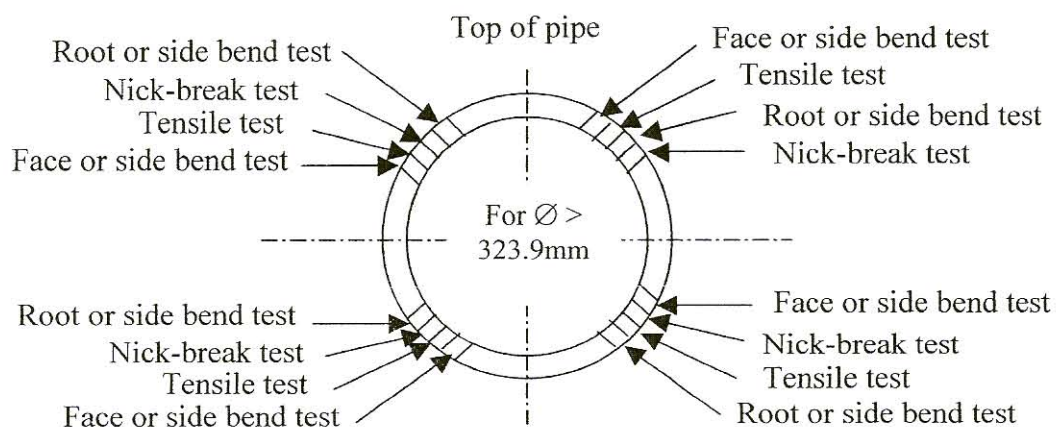
This may be exercised over welding operations by stipulating a number of elements that must be adhered too during manufacture i.e. Control of the welding preparation type is a major element in the costing of welding, with single sided welds having double the volume of some double sided welds. The result of *no control* in this area could be critical, and thus weld procedures are often used to achieve some control.

The effect of double or single sided preparations on weld volume can be seen below as in diagram *a* there are 2 triangles of equal area whilst in diagram *b* there are 4 triangles of the same area. This increase surface area or volume would have a major effect on welding production costs.



Quality Control:

In the control of quality it is generally perceived in engineering that the main function of a welding procedure is as a means of achieving and consistently maintaining a minimum level of required mechanical properties. The specific properties and their critical levels are generally laid down in the applied application standard. To achieve this, a test weld is made using a recorded set of variable parameters for the process/joint being used. After any Visual/NDT requirements have been met the specimens would be cut ready for mechanical testing. Most application standards specify type/location of specimens to be cut from the welded test piece, as with a common line pipe example below:



Documentation

Should the level of work, and thus the application standard state that a written welding procedure must be **produced, tested and retained** then this should be carried out using the following documentation, with which the welding inspector should be familiar:

pWPS **Provisional or Preliminary Welding Procedure Specification.**

A provisional welding procedure specification or pWPS is a detailed quality related document that contains all the preliminary welding data prior to approval. All data recorded on this document remains as preliminary, or provisional prior to successful completion of any required testing or examination.

WPQR **Welding Procedure Approval Record** (Also known as a PQR Procedure Qualification Record)

A WPQR or WPQR is a **quality document** that holds precise data for all essential and non-essential welding variables that were used and recorded for the test weld. It must also include all subsequent data for any PWHT and results of any mechanical tests carried out on the weldment. It is normally required that this document be stamped and signed by the mechanical test house, third party and manufacturers representative and is recorded and held in the **quality file system**.

WPS **Welding Procedure Specification**

A WPS is a **working document** that is prepared from the WPQR and then is **issued to the welder**. It contains all the essential data required by production to complete the weld successfully, achieving the minimum level of any properties required.

It is also important to note there are numerous applications where acceptable levels of manufacturing are achieved, where written and/or approved welding procedures are **not** a quality requirement, and where the selection of the appropriate welding parameters is made either by the **welder**, or **welding supervisor**, and is based upon their **experience**.

Extents of approval

An approved WPS may have an **"Extent of approval"** (Working tolerances) for some variables, of which the following are possible examples:

- | | |
|---------------------------|-----------------------------|
| 1) Thickness of plate | 2) Diameter of pipe |
| 3) Welding position | 4) Material type/group |
| 5) Amperage/voltage range | 6) Number/sequence of runs |
| 7) Consumables | 8) Heat input range (kJ/mm) |
| 9) Pre-heat | 10) Inter-pass temperature |



XYZ Fabrications Ltd
44 High St, Weldtown, Australia
ASME IX - Procedure Qualification Record (PQR)
Weldspec software by TWI

PQR record number	TWI-PQR-24	Revision	WPS record number	XYZ Fabrications Ltd	Revision
Date	20/02/2002		Company name	ASME Section IX	
			Welding standard		

BASE METALS (QW-403)

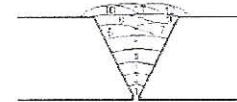
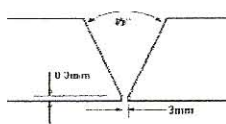
Product form	Specification (type or grade)	P no.	Qw no.	Size	Sch.	Thick. (mm)	Thick. (in)
Pipe	SA-336 (P11)	4	1	25400	120	21.44	273.05
Welded to:	Pipe	5a		25400	120	21.44	273.05
and tested	With PWHT With hardness						
Notes							

POST WELD HEAT TREATMENT (QW-407)

Temperature (°C)	710	Time (hrs)	2	Type	
Heating rate (°C/hr)	220	Method			
Cooling rate (°C/hr)	260	Method			
Notes					

JOINTS (QW-402)

Joint design	Single-V-groove				
Backing	None				
Reinforce					
Groove angle	50				
Root opening	3.2				
Root face	0-1				



WELDING PROCESSES

Welding process	GTAW	FCW
Type	Manual	Semi-automatic

FILLER METALS (QW-404)

SFA specification	628	628
AWS classification	ER80S-G	E81T1-B2
Filler metal F number	6	6
Weld metal A number	3	3
Filler metal nominal composition		
Filler metal trade name		
Filler metal size (mm)	2.4	1.2
Deposited thickness (mm)	7	1.2
Maximum pass thickness (mm)		
Weld deposit Charasity		
Supplemental filler metal		None
Supplemental filler metal vol. (mm)		None

POSITION (QW-405)

Position of groove	6G	6G
Weld progression	-	-

PREHEAT (QW-406)

Preheat temperature (°C)	150	150
Maximum interpass temperature (°C)	300	300

GAS (QW-408)

Shielding gas	Type	Argon 99.99%	Argon 99.99%
Flow rate	(mm)	15-20	15-20
Trailing gas	Type	None	None
Flow rate	(mm)	-	-
Backing gas	Type	Argon 99.99%	None
Flow rate	(mm)	8-15	-

ELECTRICAL (QW-409)

Filler metal size (mm)	2.4	2.4	1.2	1.2	1.2
Amps	150	180	180	150	170
Volts	16	17	23	25	24
Travel speed (mm/min)	60	120	180-220	170-200	210-270
Maximum heat input (kJ/mm)	1.8	1.52	1.13-1.55	1.43-1.68	0.91-1.17
Tungsten size (mm)		2.4			
Tungsten type		SFA 5.12 EWTh2			
Current/polarity	DCSP	DCSP	DCRP	DCRP	DCRP
DC pulsing current	Not used	Not used			
Wire feed speed (mm/min)					
Arc transfer mode				Spray	

TECHNIQUE (QW-410)

String or weave	Stringer and Weave	Stringer and Weave
Orifice/gas cup size	No. 5-8	No. 12-20
C T W D		
Multi/Single pass per side	Multiple passes	Multiple passes
Peening	Not used	Not used
Initial/Interpass cleaning	Brushing/Chipping/Grinding	Brushing/Chipping/Grinding
Back gouging method	Not applicable	Not applicable

XYZ Fabrications Ltd		XYZ Fabrications Ltd	
44 High St, Weldtown, Australia		44 High St, Weldtown, Australia	
ASME IX - Procedure Qualification Record (PQR) - Test results (PWHT)			
Weldspec software by TWI			
PQR record number	TWI-PQR-24	Revision	Revision
Date	26/09/2002	WPS record number	XYZ Fabrications Ltd
		Company name	ASME Section IX
		Welding standard	
TENSILE TESTS (QW-150)			
Specimen number	Width (mm)	Thickness (mm)	Area (mm ²)
1	19.3	20.6	391.40
2	19.3	20.5	389.60
Specified			
Ultimate total load (kN)	Ultimate and stress (MPa)	Type of failure and location	
	537.5	Ductile-BM	
	535.6	Ductile-BM	
	413		
Comments: 2 reduced section tension tests per QW-151.2 and QW-462.1(c)			
GUIDED BEND TESTS (QW-160)			
Type of test	Acceptance criteria	Result	Comments
4 transverse side bends per QW-161.1 and QW-462.2	QW-163	Acceptable	see - ASME IX - QW-461.1
Comments: Dimensions - 9.5 x 22.6, 9.5 x 22.7, 9.5 x 22.7, 9.5 x 22.8. Bend - 180 deg. Mandrel diameter - 36mm			
HARDNESS TEST			
Type (Scale)	Distance from surface	SA-336 (P11)	HAZ
Vickers (HV5)		169, 186	192, 227
		171, 181	225, 237
		183, 169	244, 246
		179, 179	235, 270
		174, 183	236, 262
		174, 192	224, 228
Comments: See Report No. 1002-08-00			
OTHER TESTS			
Type of test	Acceptance criteria	Result	Comments
Radiographic examination per QW-191 and QW-302.2	QW-191.2	Acceptable	see - ASME IX - QW-142.3, QW-304.5
Penetrant test		Acceptable	
Macro examination		Good	
Comments: Report Nos. - RT-PQT-S-1, P1-PQT-S-01 - Radiograph Nos. - WP-BQ-03, S-1, 1-2, 2-3, 3-4, 4-5			
CERTIFICATION			
Welder's name	ID Number	Stamp number	Notes
J. Smith			
Mechanical testing by			Notes
Laboratory test number			
Test file number			
Tests conducted by			

We certify that the statements in this record are true and tested in accordance with TWI's ISO 9001 and ISO 14001

Welding Engineer		QA Manager	
Name	Signature	Name	Signature
SY5	<i>Fred Bloggs</i>		
Date		Date	
23/01/2004			
Certified by			
Name	Signature		
Date			

Weldspec 4.10.234

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Page 2 of 2

Welder Approval:

A welder approval test is used to test of the level of skill attained by the welder.

Once a welding procedure has been approved it is important to ensure that all welders employed in production can meet the level of quality set down in the application standard. Welder approvals are carried-out, where the welders are directed to an approved **WPS** by the welding inspector who also acts as the witness. Upon completion of the test plate, or pipe it is generally tested for internal/external quality using visual examination, then **NDT** generally using ***Radiography or Ultra-sonic Testing*** then followed by some basic ***Qualitative*** mechanical/destructive tests, in that order, with the amount of testing being dependent on the level of **skill** demanded from the welder by the application standard.

It should also be noted that welder approval tests are possible when using unapproved welding procedures, as with **BS 4872 "Welder Approval When Procedural Approval Is Not Required"** Whilst the welding procedure remains unapproved it must in this instance be written. (Page 5:8 shows an example **BS 4872** Welder Approval Certificate) The mechanical tests in a welder approval *could* include some of the following:

- | | |
|--|---------------------------------------|
| a) Bend tests (Side Face or Root) | b) Fillet weld fracture tests |
| c) Nick break tests | d) Macrograph assessment tests |

When supervising a welder test the welding inspector should:

- 1) Check that extraction systems, goggles and all safety equipment are available
- 2) Check the welding process, condition of equipment and test area for suitability
- 3) Check grinders, chipping hammers, wire brush and all hand tools are available
- 4) Check materials to be welded are correct and stamped correctly for the test
- 5) Check consumables specification, diameter, and any baking pre-treatments
- 6) Check the welder's name and identification details are correct
- 7) Ensure any specified preheat has been applied, and is measured correctly
- 8) Check that the joint has been correctly prepared and tacked, or jigged
- 9) Check that the joint and seam is in the correct position for the test
- 10) Explain the nature of the test and check that the welder understands the WPS
- 11) Check that the welder completes the root run, fill and cap as per the WPS
- 12) Ensure welders identity and stop start location are clearly marked
- 13) Supervise or carry out the required tests and submit results to Q/C department.

Examples of typical *Welder Performance/Approval Qualification/Certificates* to ASME IX and BS 4872 are shown below on pages 5.7 and 5.8 respectively:



XYZ Fabrications Ltd
44 High St, Weldtown, Australia
ASME Section IX - Welder Performance Qualification (WPQ)
Welderqual software by TWI Ltd

Welder's name ID Number Date of birth Stamp number Company name Division	Stephen Jenkins 113 7.10.1971 1003215-81 XYZ Fabrications Ltd Welding shop		Test date WPQ record number Standard test number WPS record number Qualification code	07/11/2002 TWI-WPQ-17 NA NA ASME Section IX	Rev. Rev.
---	---	---	---	---	--------------

BASE METALS (QW-403)

	Product form	Specification (type or grade)	P no.	Qip no.	Size	Sch.	Thick. (mm)	Dia. (mm)
Welded to:	Pipe	SA-106 (B)	1	1	101.60	Standard	6.02	114.30
	Pipe	SA-106 (B)	1	1	101.60	Standard	6.02	114.30
Joint type	Groove							

VARIABLES	Actual values	RANGE QUALIFIED
Type of weld joint	Pee - Groove P1 to P1	Groove and Fillet welds Pee / Saws 1 thru 11, 34, 41 thru 47
Base metal		

BASE METAL THICKNESS	Groove	Fillet	Overlay	Groove	Fillet	Overlay
Plate thickness (mm)	-	-	-	no limit	no limit	-
Pipe/tube thickness (mm)	6.02	-	-	no limit	no limit	-
Pipe diameter (mm)	114.30	-	-	73 mm	no limit	-

PROCESS VARIABLES	Actual values	RANGE QUALIFIED
Welding process	GTAW	GTAW
Type	Manual	Manual
Backing	With	With
Filler metal specification	518	5xx
Filler metal classification	ER70S-6	Any
Filler metal F-number	6	6
Filler metal variety (QW-404.23)	Same (solid)	Solid, metal cored
Consumable insert	None	Without
Number of layers deposited	3	
Weld deposit thickness (mm)	6.02	12.04 max
Weld position	6G	
		All
		All
		All
		All
		All
		All
Progression	Up	Up
Backing gas	Without	With, without
GTAW welding current/polarity	DCSP	DCSP

TESTS	Type of test	Acceptance criteria	Result	Comments
	2 transverse face bends per QW-181.2 and QW-462.8(a)	QW-181	Acceptable	see - ASME IX - QW-462.7 (a) Note (1)
	2 transverse root bends per QW-181.3 and QW-462.8(a)	QW-181	Acceptable	see - ASME IX - QW-462.7 (a) Note (1)
	Visual examination per QW-302.4	QW-181	Acceptable	see - ASME IX - QW-462.7 (a) Note (2)

Notes:

CERTIFICATION

Tests conducted by	Norman Smith	Laboratory test number	ADB0432-104
Mechanical tests by	ABC Testing Ltd	Test file number	

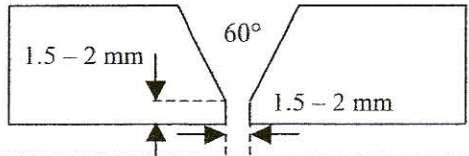
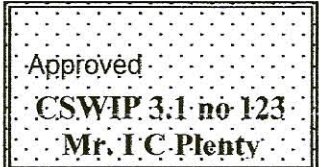
We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of Section IX of the ASME Code.

Welding Engineer
Production Manager

Name	Signature	Name	Signature
SYYS			
Date		Date	
23/01/2004			

QA

Name	Signature
Date	

Organization's Symbol Logo: 	Welder approval test certificate (BS 4872: Part 1 1982)	Test record No 321
Manufacturers name: <i>Justin Time Fabrications Ltd.</i>	Welders name & Identity No Mr. U. N. D'Cutt. Stamp 123	Issue No 001
Test piece details: Welding process: MMA 111 Parent material: Ferritic steel Thickness: 5mm Joint type: Single V butt. Pipe outside Ø: 150mm Welding position: Overhead. Vertical up. Horizontal vertical. Flat. Test piece position: Axis° inclined 45 Fixed/rotated: Fixed		Date of test 9 th September 2004
Welding consumables: Filler metal: ESAB OK 55.00 (Make & type) Composition: Ferritic steel. Specification: E 8018 Shielding gas: N/A Specification number: AWS A5.1-81		Extent of approval: Welding Process: MMA Materials Range: Ferritic steels. Thickness range: 2.5 – 10 mm. Joint types: Butt welds in plate & pipe. Pipe outside Ø: 75 - 300mm Welding Position: All except Vertical down. Consumables: Rutile & Basic.
		Weld preparation (dimensioned sketch) 
Visual examination & Test results:		
Visual Inspection:		
Contour:	<i>Acceptable</i>	Penetration (No backing)
Undercut:	<i>Acceptable</i>	Penetration (with backing)
Smoothness of joins:	<i>Acceptable</i>	Surface defects
Destructive tests:		
Macro	Side Bend	Root Bend
<i>Not required</i>	<i>Not required</i>	<i>X2 Acceptable</i>
Fillet fracture		Butt Nick break
<i>Not required</i>		<i>Not required</i>
Remarks: <i>The weld was spatter free and had a good appearance and toe blend.</i>		
The statements in this certificate are correct. The test weld was prepared in accordance with the requirements of BS 4872: Part 1 1982.		
Manufacturers Representative: Mr. Justin Time <i>Justin Time</i> Position: Production Quality Manager Date: 9 th September 2004	Inspecting authority, or test house: ABC Inspection Ltd. <i>I C Plenty</i> Tested/Witnessed by: Mr. I C Plenty Date: 9 th September 2004	
		

WIS 5 Section 5 Exercise:

- 1) List 7 other possible *Extents of Approval* of an Approved Welding Procedure?

1. Material type/group
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____

- 2) List 3 *destructive tests* that may be used after the stages of initial *visual inspection* & *NDT* have been carried out, during any welder approval test?

1. Visual Inspection
2. NDT
3. _____
4. _____
5. _____

- 3) List 4 other documents used in *welding procedure* or *welder approval* testing?

1. Provisional Welding Procedure Specification (pWPS)
2. _____
3. _____
4. _____
5. _____

WIS 5 Welding Inspection

Section 06

Materials Inspection

Materials Inspection:

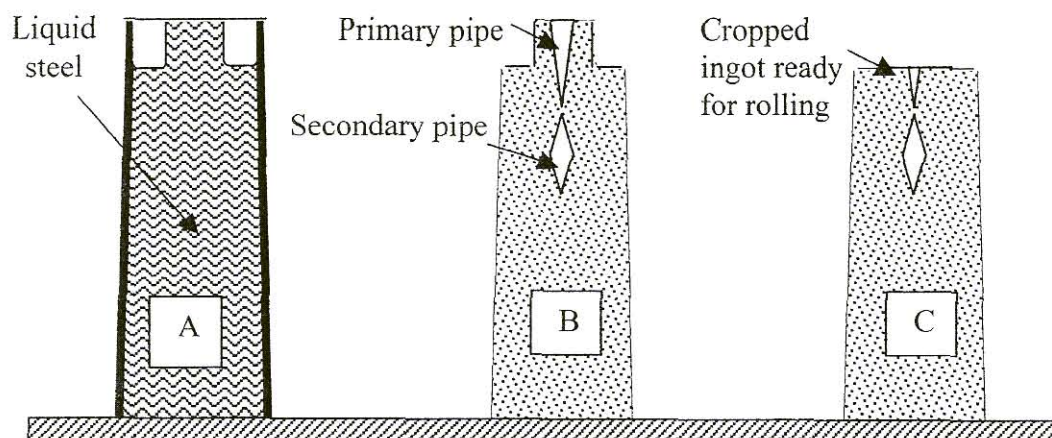
Materials

Materials are defined as solid matter that we use to make things with. There are 2 basic types of metallic materials 1) **Castings**. and 2) **Wrought Products**. Most metals and alloys commence life in the form of casting and may remain as a “**Cast Product**”

Materials with little or no ductility or malleability are normally formed in this way, such as most Cast Irons. A casting may also go on to be formed by other processes i.e. forged, hot/cold rolled, extruded, drawn and/or pressed etc. into the shapes that we are all familiar with i.e. plates, pipes and beam sections etc. (**A Wrought or Worked Product**) Imperfections may occur in cast or wrought materials due to poor refining, or incorrect application/control of a material forming process, producing a low quality metallic form.

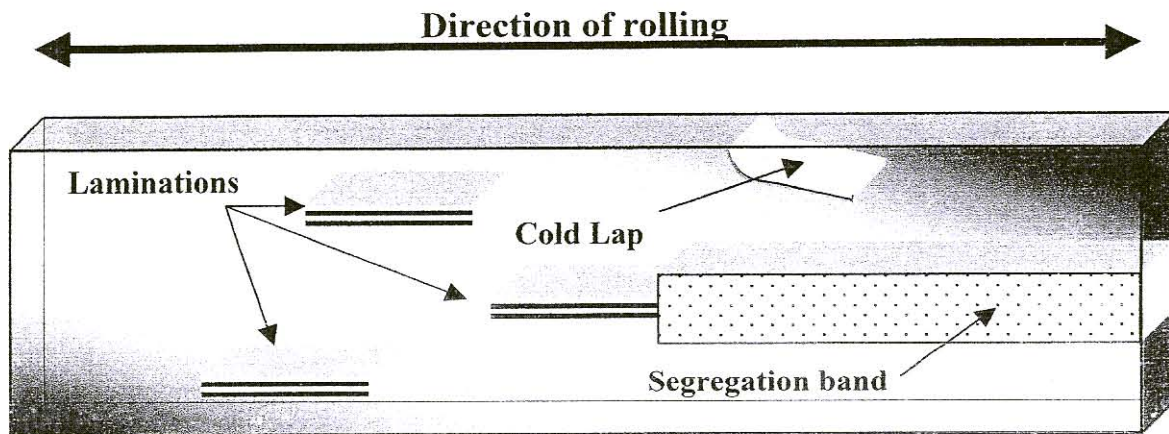
Castings:

There are many type of casting methods used to shape metals. In the conventional method of steel **ingot** casting, a ceramic lined mould is used producing a large ingot of approximately 21 metric tonnes. The mould is first fed with a charge of liquid steel as in **A** below. During the solidification process a primary pipe will be formed at the final point of cooling and solidification at the centre at the surface of the ingot and is caused by the difference in volumes between steel in the liquid and solid states. There may also be a secondary pipe formed and trapped directly beneath this as in **B** below. These pipes will also contain low melting point impurities i.e. sulphur and phosphorous and their compounds which will naturally seek the final point of solidification as they solidify at much lower temperature than the steel. Should the ingot be low quality steel, which has been poorly refined low melting point impurities held in liquid solution will **segregate** out throughout the structure at the grain boundaries and become trapped in that area by dendritic growth. Finally, the ingot would be cropped prior to primary rolling and it is very possible that due to economics and misjudgement that a portion of a primary pipe and all of any secondary pipe present will remain in the final cropped ingot as in **C** below. The cropped steel ingot would then be reheated and sent for hot rolling.



Rolling

Once an ingot has been cast it may undergo a variety of different forming methods to produce the final shape required. Very often the first of these is primary and secondary rolling. In primary rolling the heated ingot is rolled backwards and forwards through a reversing mill. The ingot is plastically deformed under compressive forces into a section until it is almost $\frac{1}{3}$ rd of the ingots CSA, though now very much longer and is termed a **bloom**. To enable the steel to deform in this manner requires a high level of the malleability, or plastic deformation under compressive forces. This is generally at an optimum in steels between the temperatures of 1100 – 1300 °C, though the exact temperatures will depend on the chemical composition of the steel. After primary rolling and working the ingot undergoes secondary rolling where it is finally cut into a number of manageable sized pieces called **billets**. During these processes any inclusions or trapped impurities in the ingot will be elongated or strung out, and may produce laminations in the final form.



Laminations contain impurities and major inclusions such as slag that solidifies in the ingot. When rolled out these major inclusions may exist throughout the plate thickness. Gas pores in the solidified ingot can also cause laminations when rolled out but will generally 'close up' during the hot rolling process. Laminations will become thinner as the plate is rolled into thinner plate and may eventually become invisible to the naked eye in thinner plates, however sulphur contents > 0.05% can cause problems in welding.

Segregation bands occur in the centre of the plate and are low melting point impurities such as sulphur or phosphorous which have segregated to the centre of the ingot as that is the last place to solidify. Great care needs to be taken when welding low quality steel as sulphur levels may be present in the steel which cannot be detected by non destructive testing. Segregation bands can only be found on etched surfaces and have an appearance similar to that of a weld HAZ.

Laps are caused during rolling when overlapped metal does not fuse to the base material due to insufficient temperature, and/or pressure.

All materials arriving on site should be inspected for

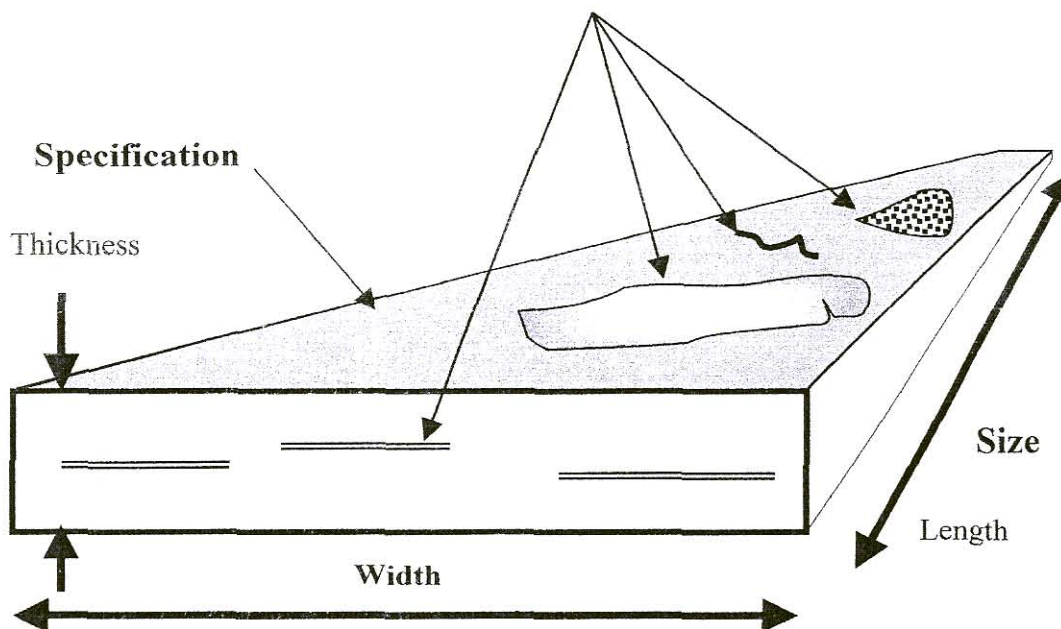
- 1) Size
- 2) Condition
- 3) Type/Specification/Schedule
- 4) Storage

In addition, other elements may need to be considered depending on the materials form or shape. Most plate materials begin life as a casting, which is then rolled out into plate, slab or billet. Plate may then be rolled into pipe and welded with a longitudinal or helical seam. Seamless pipes are generally extruded or drawn but may also be cast.

Plate Inspection

Condition

Corrosion, mechanical damage, laps, and laminations

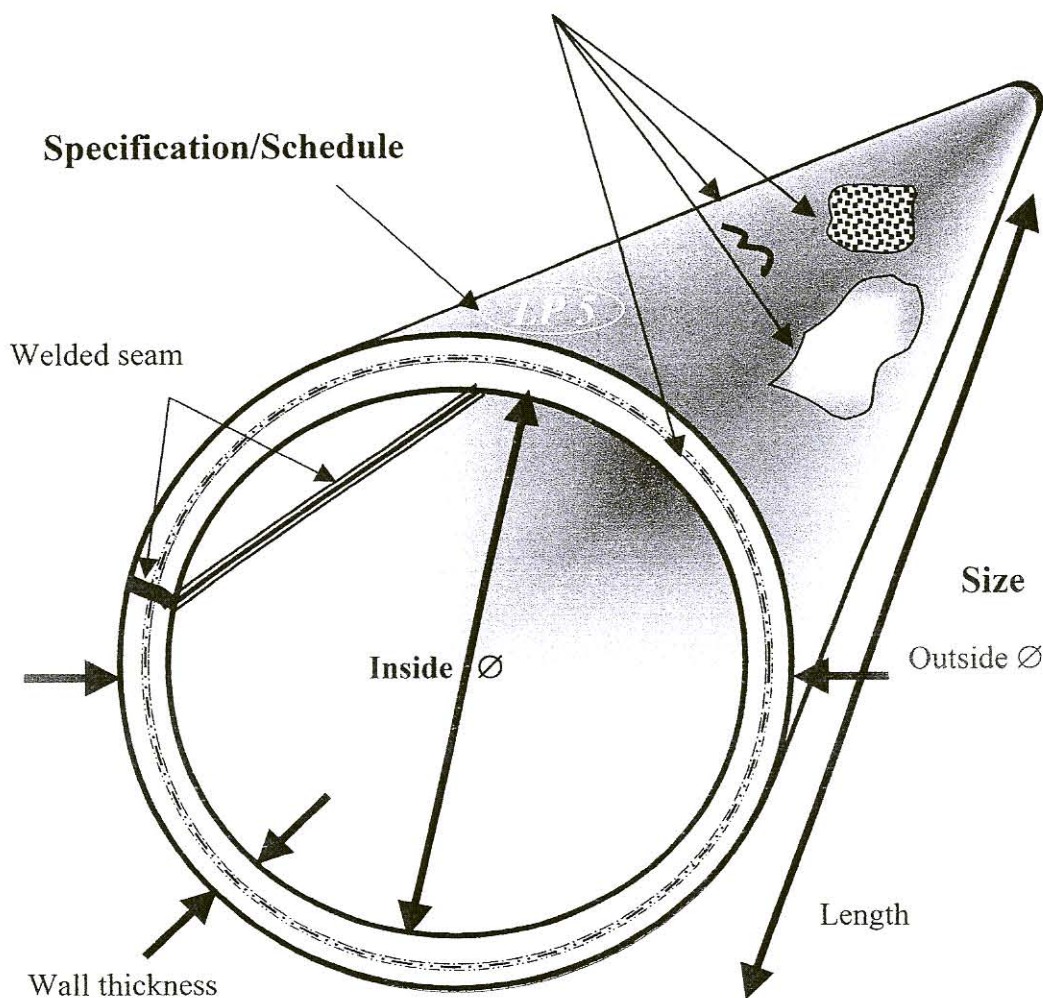


Additional checks may need to be carried out such as heat treatment, condition, distortion tolerance, quantity, storage and identification.

Pipe/Tube Inspection

Condition

Corrosion, mechanical damage, wall thickness, ovality, laps and laminations



Additional checks may also need to be carried out, such as heat treatment condition, distortion tolerance, Hi/Lo, quantity, identification and storage.

Pipe is a material form, which may be produced by one of 3 basic methods:

Seamless pipe

Helically welded pipe

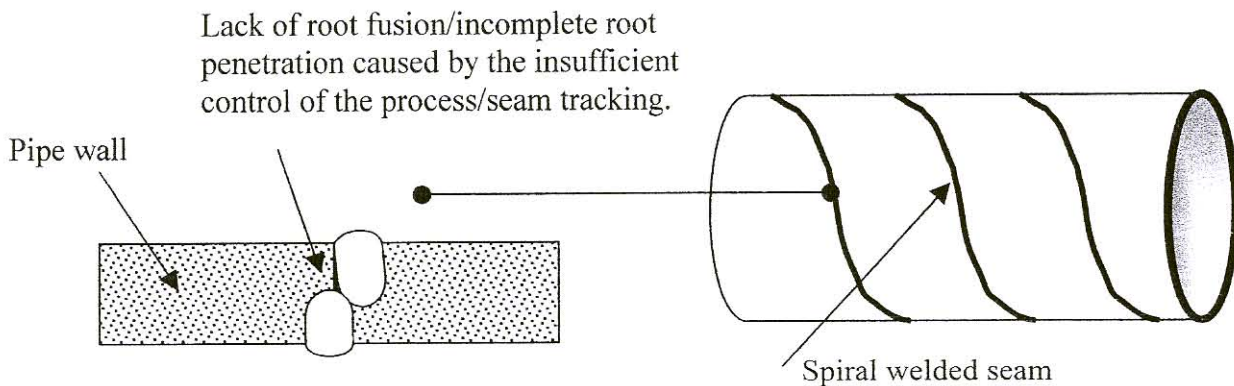
Flash butt welded pipe

Seamless pipes

Produced by the drawing or extrusion processes.

Helically welded pipes

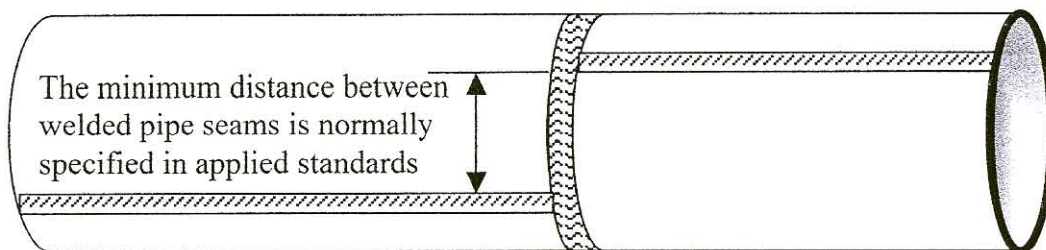
Produced from flat plate material that has been helically wound, then seam welded. The SAW process is generally used and welded on both the inside and outside of the seam at the same time. Fusion problems are commonly found on the welded seam, and are usually caused by incorrect setting of seam tracking systems. Helically welded pipes are generally of the larger diameters.



Flash-butt welded pipe

Produced from flat plate, which has then been rolled round. Problems may be found in the welded seam caused by insufficient preparation and/or poor process control.

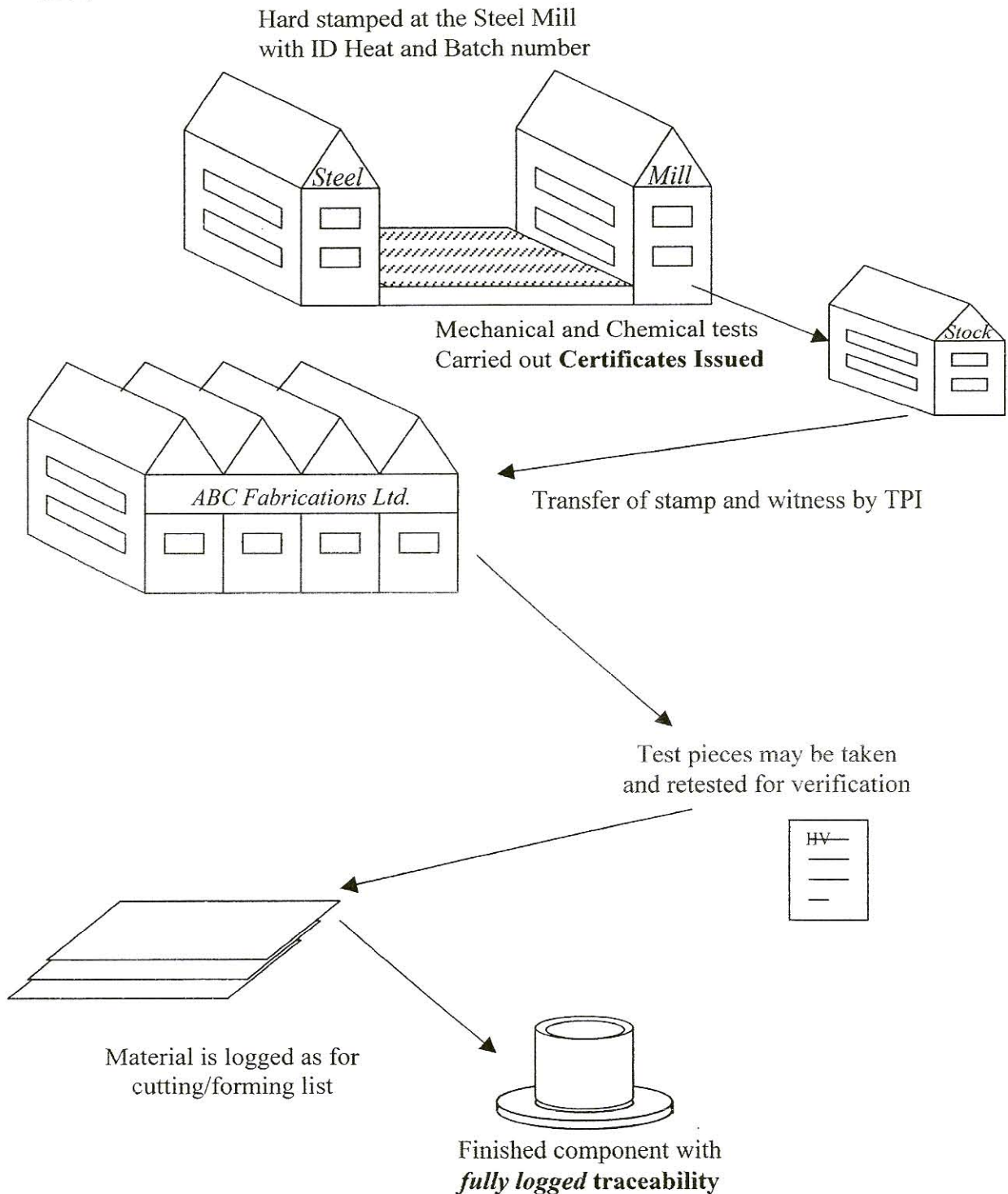
It is often a requirement of line pipe application standards that a minimum degree of distance shall be given between adjoining longitudinal seams at mating butt joints. This is generally to reduce the risk of seam bursts caused by poor fusion in the welded seam, however this will also increase the likelihood of the Hi-Lo effect in the pipe joint where any ovality had been produced in the pipes during the forming or rolling process.



The welding of pipe joint that have a high degree of Hi-Lo may cause further unacceptable welding imperfections to occur such as incomplete root penetration, or lack of root fusion. Pipes must therefore be checked carefully for acceptable levels of ovality prior to acceptance at site, as this problem may be extremely difficult to overcome once production has commenced.

Traceability

In any quality system materials need to be traceable, a very simple line diagram is shown below



WIS 5 Section 6 Exercises:

- 1) List three other main areas of inspection that the welding inspector must check for all materials arriving at the construction site?

1. Size
2. _____
3. _____
4. _____

- 2) List 2 further imperfections, which may be introduced into a material during the stages of *primary forming*?

1. Laminations
2. _____
3. _____

- 3) List 6 further inspection points of pipe materials that should be checked by the welding inspector prior to acceptance?

1. Ovality
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____

WIS 5 Welding Inspection

Section 07

Codes and Standards

Codes and Standards:

A code of practice is generally considered as a legally binding document, containing all obligatory rules required to design, build and test a specific product. A standard will generally contain, or refer to all the relevant optional and mandatory manufacturing, testing and measuring data. The definitions given in the English dictionary state:

A code of practice

A set of law's or rules that shall be followed when providing a service or product.

An application standard

A level of quality or specification too which something may be tested.

We use codes and standards to manufacture many things that have been built many times before. The lessons of failures, under or over design are generally incorporated into the next revised edition.

Typical design/construction codes and standards used in industry include:

- a) Pipe lines carrying low, and high-pressure fluids
- b) Oil storage tanks
- c) Pressure vessels
- d) Offshore structures
- e) Nuclear installations
- f) Composite concrete and steel bridge construction
- g) Vehicle manufacture
- h) Nuclear power station pipe work
- i) Submarine hull construction
- j) Earth moving equipment
- k) Building construction etc

Generally; the higher the level of quality required then the more stringent is the code/standard in terms of the manufacturing method, materials, workmanship, testing and acceptable imperfection levels. The application code/standard will give important information to the welding inspector as it determines the inspection points and stages, and other relevant criteria that must be followed, or achieved by the contractor during the fabrication process.

Most major application codes/standards contain 3 major areas, which are dedicated to the

- 1) **Design**
- 2) **Manufacture**
- 3) **Testing**

Frequently the application code/standard will contain dedicated levels of acceptance, which are drawn up by a board of professional senior engineers who operate in that specific industrial area. Others may refer to other published standards or data.

Codes and standards are revised periodically to take into account new data, new manufacturing methods, or processes that may come into being. Areas of responsibility within any application standard are generally divided into

- 1) **The client, or customer**
- 2) **The contractor, or manufacturer**
- 3) **The third party inspection authority, or client's representative**

The applied code/standard will form the main part of the contract documents hence any deviation, or non-conformance from the code/standard must be applied for by application from the contractor to the client as a concession. And should always be agreed in writing prior to implementation. Once a concession has been agreed, written and signed it is then filed with the fabrication/project quality documents.

Typical Contents of Manufacturing Standard

As previously described, most manufacturing standards can be basically divided into 3 areas, these areas will contain similar types of instructions, data, or information referenced to the production of that which the standard covers.

The sections contained within a typical *line pipe* standard are outlined below:

Section 1 General:

This section contains the *Scope* of the standard, which is a very important statement outlining accurately all that is covered by the standard, and hence indicating which is not.

Section 2 References:

This identifies a comprehensive list of all others standards, publications too which the standard makes reference. This may include nationally published standards for welding approvals, specialised equipment, welding consumables, and NDT etc.

Section 3 Definitions:

This section identifies a list of specific terms used within the standard, and offers a precise and concise explanation, or definition for each.

Section 4 Specifications:

This section gives instructions and guidance on the acceptable state, and condition of all welding equipment used on the project. It also identifies any applicable national standards for pipe materials, fittings, welding electrodes, wires, fluxes and gases etc.

Section 5 Qualification of Welding Procedure:

This section contains instructions and information relevant to the welding and testing of welding procedures. The *pWPS* would contain the following information where relevant

- a) Welding Process
- b) Base material composition and grade
- c) Diameter and wall thickness
- d) Joint design
- e) Filler material and run sequence if applicable
- f) Electrical, or flame characteristics of the welding process (As applicable)
- g) The welding position
- h) Direction of welding
- i) Time between weld passes (If applicable)
- j) Inter-run and post cleaning
- k) Pre and Post weld heat treatments (If applicable)
- l) Shielding gas and flow rates (If applicable)
- m) Shielding flux (If applicable)
- n) Speed of travel (If applicable)

The section also identifies the *essential variables*. This is defined as any variable which if changed will effect the mechanical properties of the materials being welded, thus requiring re-approval of the procedure. Essential welding variables will include:

- a) Welding process or method of application
- b) Base materials
- c) A major change in joint design
- d) A change in position from fixed to roll welded or vice –versa
- e) Wall thickness. (Outside of any extent of approval)
- f) Filler materials. (Outside of any extent of approval)
- g) Electrical characteristics
- h) Time between weld passes. (Outside of any extent of approval)
- i) Direction of welding. (For example from vertical up to vertical down)
- j) Shielding gas and flow rates. (Outside of any extent of approval)
- k) Shielding flux. (Outside of any extent of approval)
- l) Speed of travel. (Outside of any extent of approval)
- m) Pre and/or Post Heat treatment

The section may also give information relating to the location and type of tests for varying diameters of pipe and all information relating to the preparation of test pieces for mechanical testing.

Section 6 The Qualification of Welders:

This section covers aspects relating to the testing for single, and multiple qualifications of welders by Visual examination NDT and mechanical testing.

Section 7 Production Welding:

This section gives information applicable to all aspects of field production welding, covering such elements such as acceptable weather and site conditions.

Section 8 The Qualification of Inspectors and NDT Technicians:

In this section the qualification and experience requirements of all welding inspection and NDT personnel is identified.

Section 9 Levels of Acceptance:

This section contains all relevant data for the inspector to evaluate the acceptance or rejection of identified welding imperfections, through visual examination or NDT.

Section 10 Repairs:

Should a repair become necessary, this section provides guidance on the repair procedure.

Section 11 NDT Procedures:

This extensive section gives procedural instructions and information relevant to the use of Radiography, Ultrasonic testing, MPI and Penetrant testing of welded joints.

Section 12 Automatic Welding with Filler Metal Additions:

This section is dedicated to processes that do not rely upon human skill to deposit filler metal and demands an extensive amount of information similar to section 6 during welding procedural approval. Processes covered include automated MIG TIG and SAW.

Section 13 Automatic Welding Without Filler Metal Additions:

This section relates entirely to procedural approval of **flash-butt** welding of pipelines.

Application codes/standards/specifications generally **do not contain** all the relevant data required for manufacture, but may refer to other applicable standards for special elements. Examples of standards that may be referenced are given below.

- 1) **Materials specifications**
- 2) **Welding consumable specifications**
- 3) **Welding procedure approvals**
- 4) **Welder approvals**
- 5) **Personnel qualifications for NDT operators**
- 6) **NDT Methods**
- 7) **Weld Symbols on Drawings**
- 8) **Levels of acceptance of welding imperfections**

WIS 5 Section 7 Exercise 1:

List all the sections contained within your working application code or standard?

1. **The Scope** (Generally the first section heading in any code or standard) _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____
9. _____
10. _____
11. _____
12. _____
13. _____

WIS 5 Section 7 Exercise 2:

Read your nominated application standard *carefully*, identifying all sections or clauses within the standard containing acceptance/rejection *information/criteria* for the welding imperfections listed in the tables below; then insert this into the relevant columns given below in tables 1 & 2.

Table 1 Defect/Imperfection Type	Section/Clause, or Table N°
Reinforcement (Height)	
Reinforcement (Appearance)	
Incomplete filling	
Slag Inclusions	
Undercut	
Surface Porosity	
Cracks	
Lack of sidewall fusion	
Arc strikes	
Mechanical damage	
Misalignment	
Penetration (Height)	
Incomplete Root Penetration	
Lack of Root Fusion	
Root Concavity	
Root Undercut	
Burn-through	

Table 2: Defect/Imperfection Type	Maximum Allowance
Reinforcement (Height)	
Reinforcement (Appearance)	
Incomplete filling	
Slag Inclusions	
Undercut	
Surface Porosity	
Cracks	
Lack of sidewall fusion	
Arc strikes	
Mechanical damage	
Misalignment	
Penetration (Height)	
Incomplete Root Penetration	
Lack of Root Fusion	
Root Concavity (<i>Example</i>)	<i>Radiographic Density</i>
Root Undercut	
Burn-through	

Note:

In many Line Pipe Standards (API 1104) the root can only be evaluated through Radiography. Therefore some allowances, other than length are given as a factor of Radiographic Density. In such cases the imperfection should be recorded but accepted, if the Radiograph is unavailable. Imperfections that are not given in a standard should be marked as Not Referenced and Accepted.

The complete weld evaluation form can be found in the Section 23 “Practical Visual Inspection” where it forms part of page 3 of 3 of the inspection form set for both Plate and Pipe inspection. It is important that you become very conversant with these values and where the clauses and tables can be found before attempting your examination.

Warning:

No other papers can be brought into the exam room other than the application standard, which will then be checked prior to the examination for any entries made other than the printed text. If such entries are found then ejection from the exam may result. (A Hi-lighted text is acceptable)

WIS 5 Welding Inspection

Section 08

Welding Symbols on Drawings

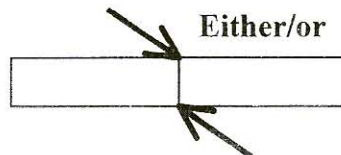
Weld Symbols on Drawings:

We use weld symbols to *transfer information* from the design office to the workshop.

It is **essential** that a welding inspector can interpret weld symbols, as a large proportion of the welding inspectors time will be spent checking that the welder is correctly completing the weld in accordance with the approved fabrication drawing. Therefore without a good knowledge of weld symbols, a welding inspector is **unable to carry out his full scope of work**. Standards for weld symbols do not follow logic, but are based on simple conventions. There are many different standards for weld symbols, as most major manufacturing countries have developed their own. It is important to understand the basic differences, and to be able to recognise a drawing standard being used. Reference should be always be made to the standard for specific symbolic information. Basically a weld symbol is made of **5** different components, common to all major standards.

1) The arrow line

The arrow line is always a **straight** and **unbroken** line, (With the exception of instances in AWS A2.4) and has only 1 of 2 points on the joint where it **must** touch, as shown below:



2) The reference line

The reference line **must** touch the arrow line, and is generally parallel to the bottom of the drawing. There is therefore always an angle between the arrow line and reference line. The point of the joint of the 2 lines is referred to as the *knuckle*.



3) The symbol

The orientation of the symbol on the line is generally the same in most standards, however the concept of **arrow side** and **other side** is shown differently in some standards. This convention is explained within the following text for UK, European, and ISO standards. (AWS A2.4 convention for arrow and other side follows that of BS 499)

4) The dimensions

Basically, all cross sectional dimensions are given to the left, and all liner dimensions are given to the right hand of the symbols in most standards.

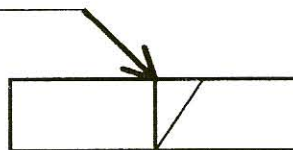
5) Supplementary information

Supplementary information, such as welding process, weld profile, NDT, and any special instructions may differ from standard to standard. The following section gives a guide to the standards used in UK and Europe.

1) Convention of BS 499 (UK)

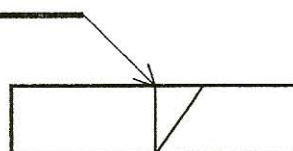
The Arrow Line

- Shall** touch the joint intersection
- Shall** not be parallel to the drawing
- Shall** point towards a single plate preparation



The Reference Line

- Shall** join the arrow line
- Shall** be parallel to the bottom of the drawing



The Weld Symbol

- Welds done from **this side** (Arrow side) of joint go **underneath** the reference line
- Welds done from the **other side** of the joint go **on top** of the reference line
- Symbols with a vertical line component must be drawn with the vertical line drawn to the left side of the symbol
- All cross sectional dimensions are shown to the left of the symbol
Fillet throat thickness is preceded by the letter **a** and the leg length by the letter **b**

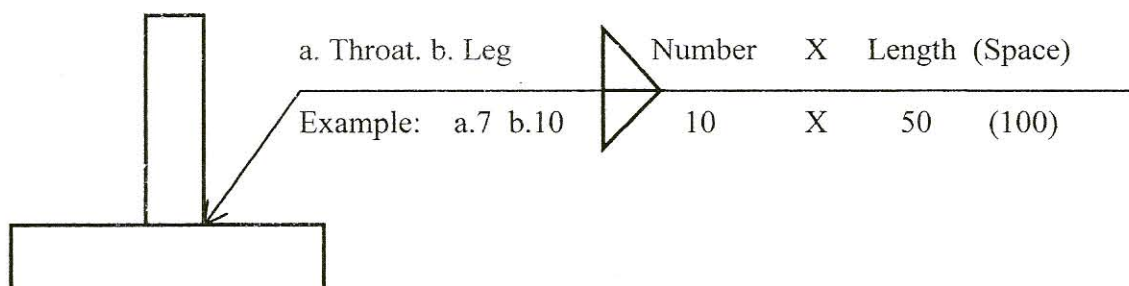
When only leg length is shown the reference letter (b) is optional

The throat thickness for partial penetration **butt** welds is preceded by the letter **s**

- All linear dimensions are shown on the right of the symbol

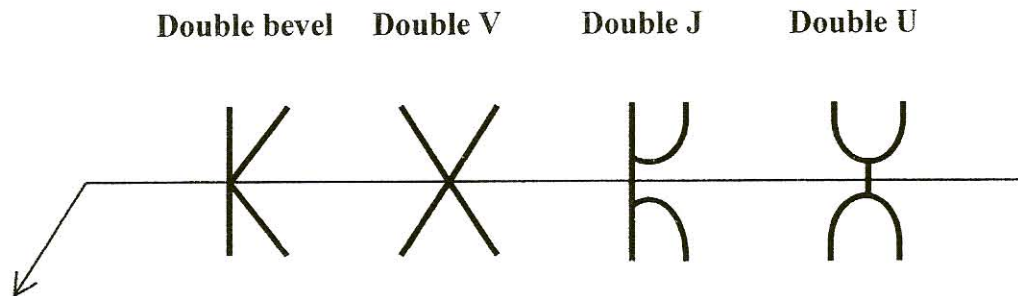
i.e. Number of welds, length of welds, length of any spaces

Example:

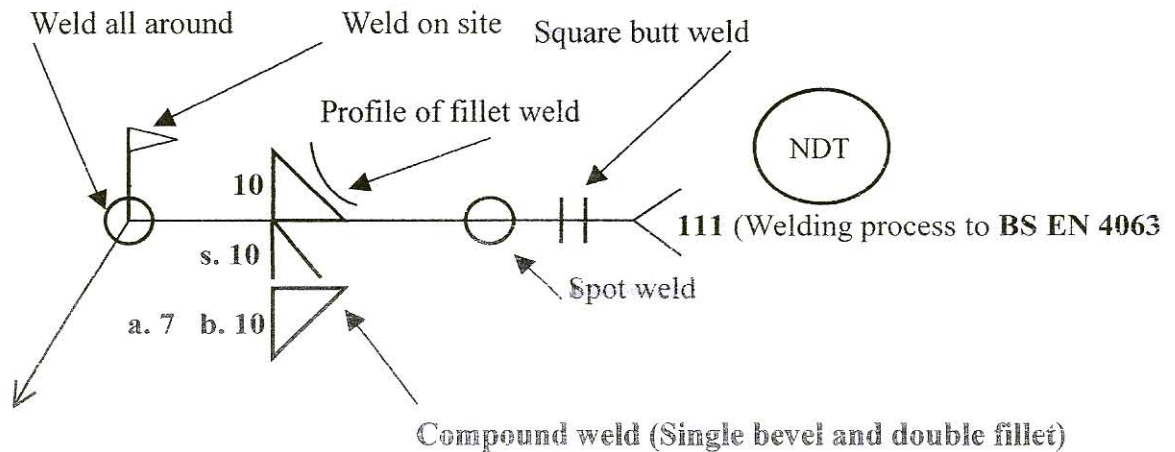


Examples of Weld Symbols common to BS 499 and BS EN 22553

Double-sided butt weld symbols

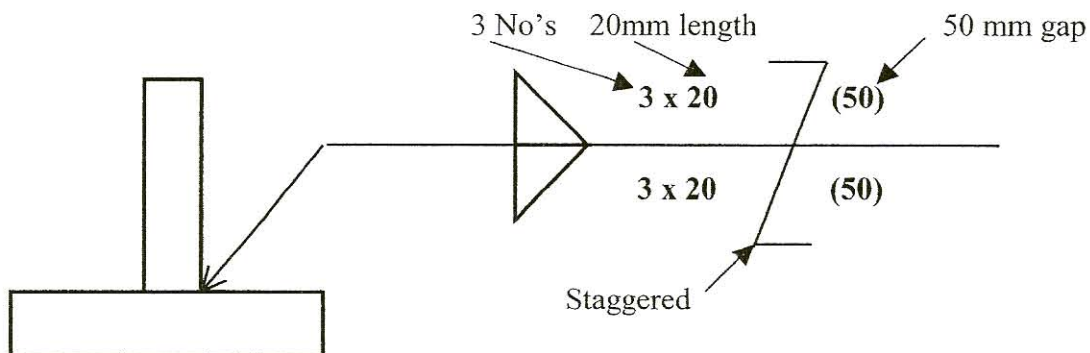


Supplementary & further weld symbols



Intermittent welds in BS 499 and BS EN 22553 are given as shown as below with number of welds x length of each weld and gap length given in brackets i.e. 3 x 20 (50)

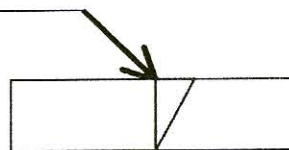
A **staggered intermittent** weld may be shown with a **Z** drawn across the axis between the weld length and gap.



2) Convention of BS EN 22553 (Has replaced BS 499 in UK)

The Arrow Line (As for BS 499)

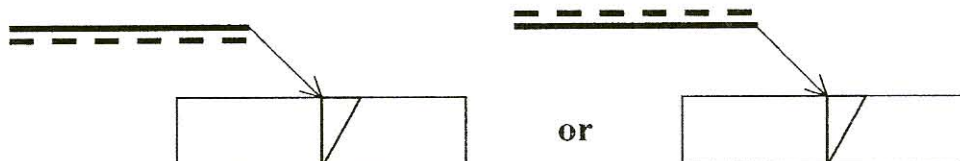
- Shall touch the joint intersection
- Shall not be parallel to the drawing
- Shall point towards a single plate preparation



The Reference Line

- Shall join the arrow line
- Shall be parallel to the bottom of the drawing
- Shall have a broken line placed above, or beneath the reference line

} As per BS 499



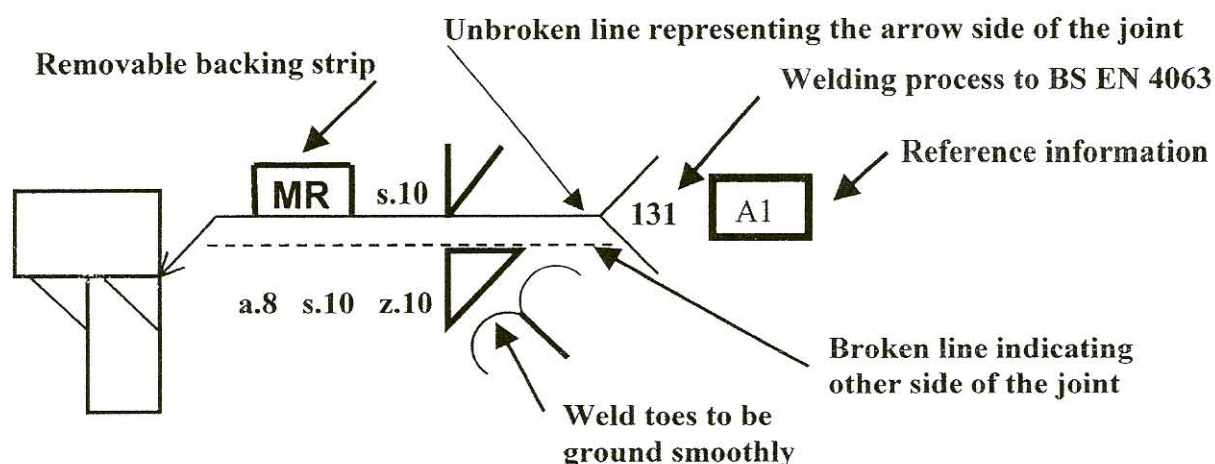
The Symbol (As for BS 499 with the following exceptions)

The other side of the joint is represented by the **broken line**, which shall be shown **above or below** the reference line, **except** in the case where the welds are totally **symmetrical** about the central axis of the joint.

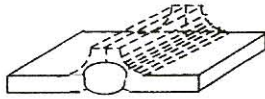
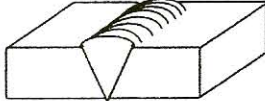
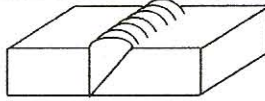
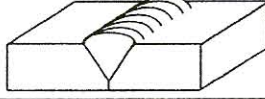
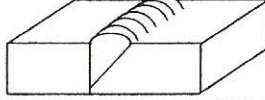
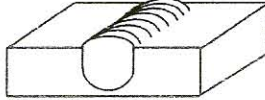
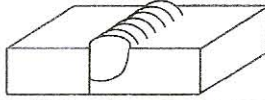
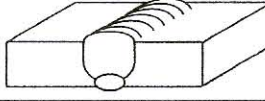
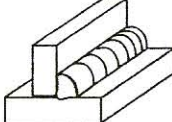
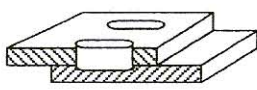
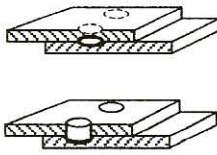
Fillet weld leg length shall always be preceded by the letter **Z**.

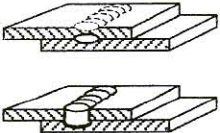
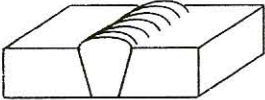
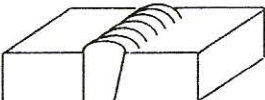
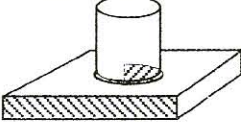
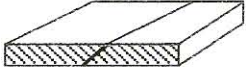
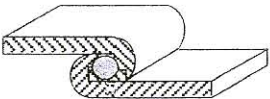
Nominal fillet weld throat thickness shall always be preceded by the letter **a**.

Effective throat thickness shall always be preceded by the letter **s** for deep penetration fillet welds and partial penetration butt welds.



Elementary Symbols as extracted from BS EN 22553

Number	Designation	Illustration	Symbol
1	Butt weld between plates with raised edges. 1 Edge flanged weld USA. The raised edges being melted down completely		
2	Square Butt Weld		
3	Single-V Butt Weld		
4	Single-bevel Butt Weld		
5	Single-V Butt Weld With a Broad Root Face		
6	Single-bevel Butt Weld With a Broad Root Face		
7	Single-U Butt Weld (Parallel or Sloping Sides)		
8	Single J-Butt Weld		
9	Backing run Backing Weld USA		
10	Fillet Weld		
11	Plug Weld; Plug Slot Weld USA		
12	Spot Weld		

13	Seam Weld		
14	Steep Flanked Single-V Butt Weld. (Narrow Gap Preparation)		
15	Steep-flanked Single-bevel Butt Weld. (Narrow Gap Preparation)		
16	Edge Weld		
17	Surfacing		
18	Surface Joint		
19	Inclined joint		
20	Fold Joint		

Supplementary Symbols Extracted from BS EN 22553		
	Shape of weld surface or weld	Symbol
a)	Flat (Usually finished flush)	
b)	Convex	
c)	Concave	
d)	Toes <i>shall</i> be ground smoothly	
e)	Permanent backing strip	
f)	Removable backing strip	

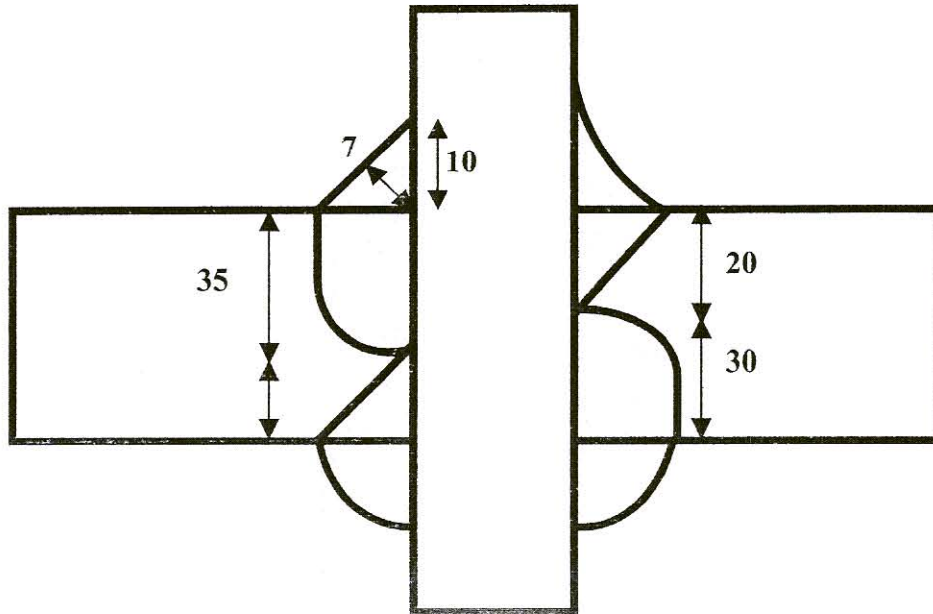
Numerical Indications of Selected Welding Processes (As extracted from BS EN 4063:2000)

No.	Process	No.	Process
1	ARC WELDING	5	BEAM WELDING
11	Metal-arc welding without gas protection.	51	Electron beam welding
111	Metal-arc welding with covered electrode	511	Electron beam welding in a vacuum
112	Gravity arc welding with covered electrode	512	Electron beam welding out of vacuum
114	Flux cored metal-arc welding	52	Laser welding
12	Submerged arc welding.	521	Solid state LASER welding
121	Submerged arc welding with 1 wire electrode	522	Gas LASER welding
122	Submerged arc welding with strip electrode		
123	Submerged arc welding with multi electrodes	7	OTHER WELDING PROCESSES
124	Submerged arc welding + metallic powders	71	Alumino-thermic welding (Thermit)
125	Submerged arc welding tubular cored wire	72	Electro-slag welding
13	Gas shielded metal-arc welding	73	Electro-gas welding
131	MIG welding: (With an inert shield gas)	74	Induction welding
135	MAG welding: (With an active gas shield)	75	Light radiation welding
136	Flux cored arc welding (With an active gas shield)	77	Percussion welding
137	Flux cored arc welding (With an inert gas shield)	78	Stud welding
14	Gas-shielded welding (Non-consumable electrode)	782	Resistance stud welding
141	TIG welding		
15	Plasma arc welding	8	CUTTING & GOUGING
151	Plasma MIG Welding	81	Flame cutting
152	Powder Plasma Arc Welding	82	Arc cutting
18	Other arc welding processes	821	Air Arc cutting
185	Magnetically Impelled Arc Butt Welding	822	Oxygen Arc cutting
		83	Plasma cutting
2	RESISTANCE WELDING	84	Laser cutting
21	Spot welding	86	Flame gouging
22	Seam welding	87	Arc Gouging
23	Projection welding	871	Air-Arc Gouging (Using Carbon Electrodes)
24	Flash welding	872	Oxy-Arc gouging
25	Resistance butt welding	88	Plasma gouging
29	Other resistance welding processes		
		9	BRAZING, SOLDERING & BRAZE WELDING
3	GAS WELDING	91	Brazing
31	Oxy-fuel gas welding	912	Flame brazing
311	Oxy-acetylene welding	913	Furnace brazing
313	Oxy-hydrogen welding	914	Dip brazing
32	Air fuel gas welding	93	Other brazing processes
		94	Soldering
4	WELDING WITH PRESSURE	942	Flame soldering
41	Ultrasonic welding	952	Soldering with soldering iron
42	Friction welding	96	Other soldering processes
44	Welding by high mechanical energy	97	Braze welding
45	Diffusion welding	971	Gas braze welding
47	Gas pressure welding	972	Arc braze welding
48	Cold pressure welding		

WIS 5 Section 8 Exercises:

Complete a symbols drawing for the welded cruciform joint given below

All butt weld are welded with the MIG process and fillet welds with MMA.



All fillet weld leg lengths are 10 mm

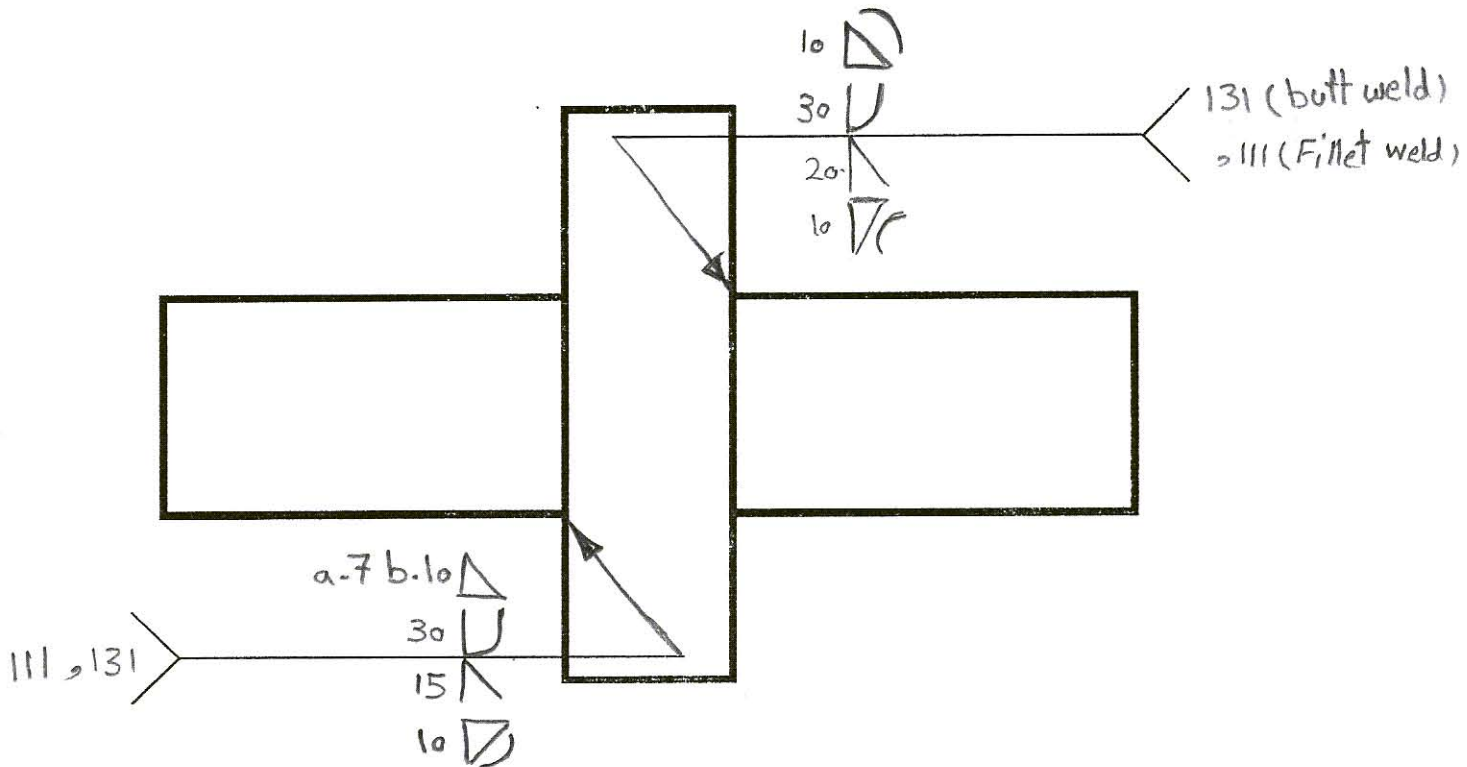
Use the sheets overleaf to transcribe the information shown above into weld symbols complying with the following standards

BS 499 Part II
BS EN 22553

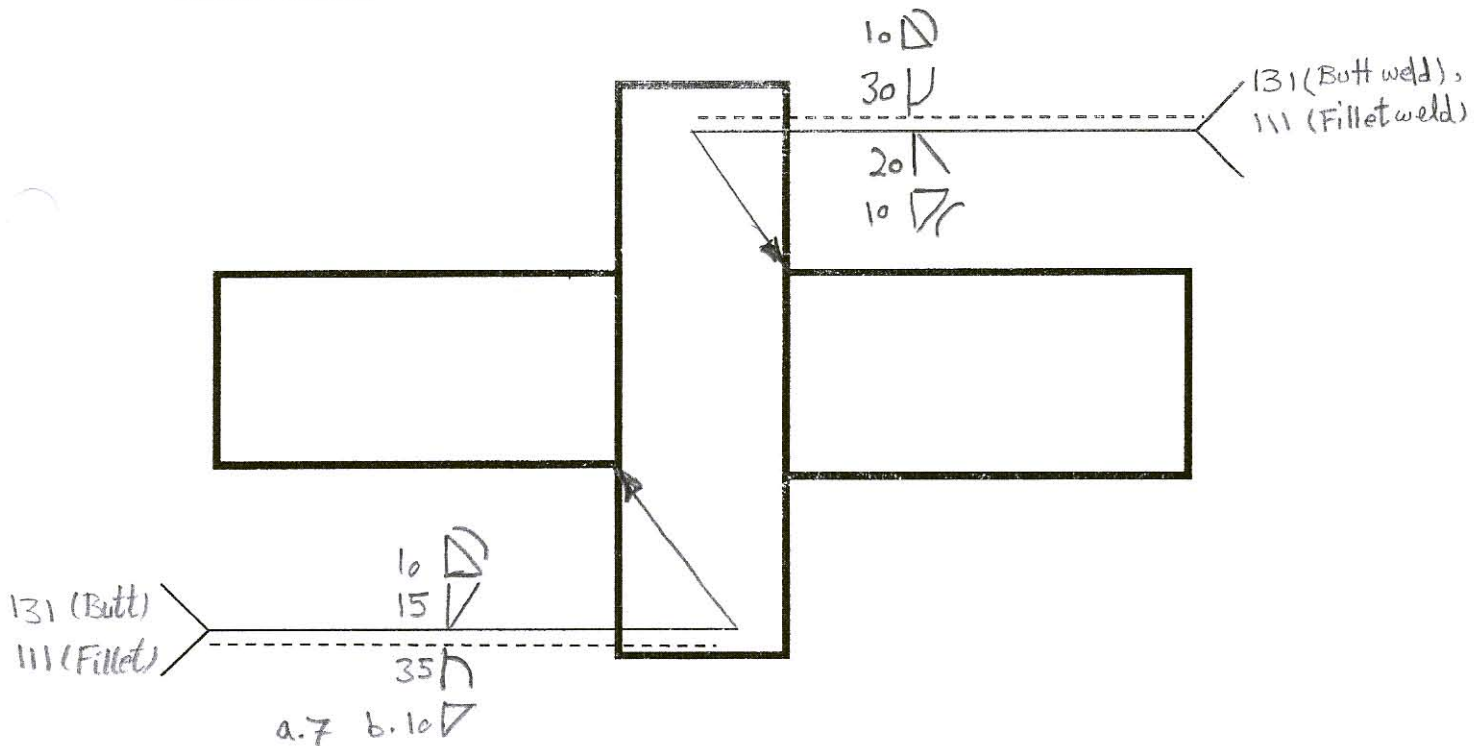
Use the drawings provided overleaf

The course lecturer will present the solutions, after you have completed the exercise.

BS 499 Part II



BS EN 22553



WIS 5 Welding Inspection

Section 09

Introduction to Welding Processes

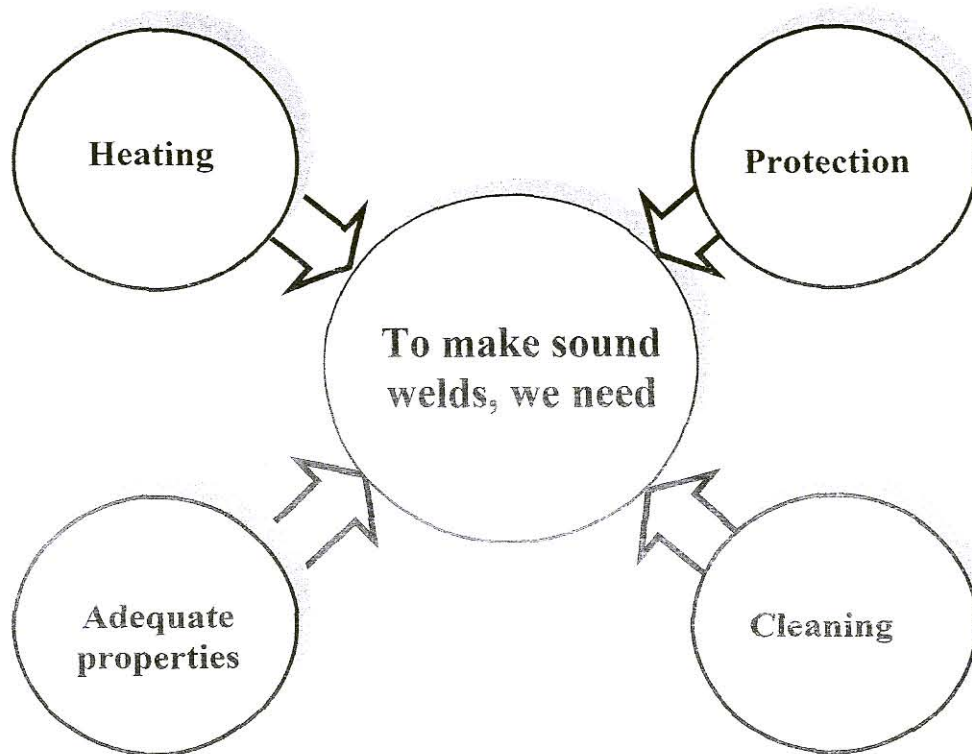
Introduction to Welding Processes:

A Welding Process: Special equipment used with method, for producing welds.

Welding processes are classified into 2 specific areas

- 1) **Fusion Welding processes.** (The weld requires **melting/mixing** and re-solidification)
- 2) **Solid Phase/State Welding processes.** (The weld is made in the **plastic condition**)

The 4 main requirements of any Fusion Welding Process are



Protection	Of the molten filler metal in transit and base metal from oxidation, and to protect the weld zone from ingress of gases such as hydrogen & oxygen
Cleaning	Of the weld metal to remove oxides and impurities, and refine the grains
Adequate properties	Adding alloying elements to the weld, to produce the desired mechanical properties
Heating	Of high enough intensity to cause melting of base metals and filler metals

Protection: *Of the heat source and weld area from oxidation*

In MMA welding, the gas shield is produced from the combustion of compounds in the electrode coating. The gas produced is mainly CO₂ but electrodes are available that produce varying amounts of hydrogen gas, which gives higher levels of penetration.

In Submerged Arc welding the gas shield is again produced from the combustion of compounds, but these compounds are supplied in a granulated flux, which is supplied separately to the wire. MMA electrodes or SAW fluxes containing high levels of basic (calcium) compounds are used where either hydrogen control, or high toughness and strength has been specified as most basic agents have a very good cleaning effect.

In MIG/MAG & TIG welding the gas is supplied directly from a cylinder, or bulk feed system and may be stored in a gaseous, or liquid state. In TIG & MIG welding we generally use the inert gases argon or helium. In MAG welding we generally use CO₂ or mixtures of CO₂ or O₂ in argon.

Cleaning: *Of surface contaminants & refinement of weld metal*

The cleaning, refining and de-oxidation of the weld metal is a major requirement of all common fusion welding processes. As a weld can be considered as a casting, it is possible to use low quality wires in some processes, and yet produce high quality weld metal by adding cleaning agents to the flux. This is especially true in MMA welding, where many cleaning agents and de-oxidants may be added directly to the electrode coating. De-oxidants and cleaning agents are also generally added to FCAW & SAW fluxes. For MIG/MAG & TIG welding wires, de-oxidants, such as silicon, aluminium and manganese must be added to the wire during initial casting. Electrodes and wires for MIG & TIG welding must also be refined to the highest quality prior to casting, as they have no flux to add cleaning agents to the solidifying weld metal.

Properties: *Of sufficient values, produced through alloying*

As with de-oxidants, we may add alloying elements to the weld metal via a flux in some processes to produce the desired weld metal properties. It is the main reason why there is a wide range of consumables for the MMA process. The chemical composition of the deposited weld metal can be changed easily during manufacture of the flux coating. This also increases the electrode efficiency. (Electrodes of > 160% are not uncommon for surfacing applications). In SAW, compounds such as Ferro-manganese are added to agglomerated fluxes. It is much cheaper to add alloying elements to the weld via the flux as an ore, or compound. As with the cleaning requirement described above, wires for MIG/MAG & TIG must be drawn as cast, thus all the elements required in the deposited weld metal composition must be within the cast and drawn wire and is the main reason why the range of these consumables is very limited. With the developments of flux core wires, the range of consumables for FCAW is now more extensive, as alloying elements may be easily added to the flux core in the same way as MMA electrodes fluxes.

Heating: *Sufficiently high for the type of welding being done*

There are many heat sources used for welding. In fusion welding, the main requirement of any **fusion welding process** is that the heat source must be of sufficient temperature to **melt** the materials being welded.

The intensity of this heat is also a major factor, which will mainly affect the speed of the welding operation. This section briefly describes some of the various types of fusion and solid phase welding processes available to the Welding Engineer.

In BS EN 4063 Welding/Cutting Processes are classified, or grouped as follows

No	WELDING PROCESS MAIN GROUP
1	ARC WELDING
2	RESISTANCE WELDING
3	GAS WELDING
4	WELDING WITH PRESSURE
5	BEAM WELDING
7	OTHER WELDING PROCESSES
8	CUTTING & GOUGING
9	BRAZING, SOLDERING & BRAZE WELDING

The common group of welding processes are shown above as categorised in BS EN 4063. Some of the more common specific processes that fall within these groups are explained further within this section.

These main groups are divided into subsections of smaller groups relying on the same method of heating, which may themselves have sub divisions i.e.

1	Arc Welding
13	Gas shielded metal-arc welding
131	MIG welding: (With an inert shield gas)

The most common group used for welding of plate/pipe materials uses the *electric arc* as the main heating method. This is mainly due to portability and relative ease of electrical power generation or the use of using readily available electrical power supplies with some added equipment, which in its most basic adaptation of the arc process as Manual Metal Arc Welding may be as simple as a transformer/rectifier, 2 x high duty cycle electrical copper leads, an electrode holder, a power return clamp, a consumable electrode, and a suitably shaded visor.

1) Arc Welding

1	ARC WELDING
11	Metal-arc welding without gas protection.
111	Metal-arc welding with covered electrode
112	Gravity arc welding with covered electrode
114	Flux cored metal-arc welding
12	Submerged arc welding.
121	Submerged arc welding with 1 wire electrode
122	Submerged arc welding with strip electrode
123	Submerged arc welding with multi electrodes
124	Submerged arc welding + metallic powders
125	Submerged arc welding tubular cored wire
13	Gas shielded metal-arc welding
131	MIG welding: (With an inert shield gas)
135	MAG welding: (With an active gas shield)
136	Flux cored arc welding (With an active gas shield)
137	Flux cored arc welding (With an inert gas shield)
14	Gas-shielded welding (Non-consumable electrode)
141	TIG welding
15	Plasma arc welding
151	Plasma MIG Welding
152	Powder Plasma Arc Welding
18	Other arc welding processes
185	Magnetically Impelled Arc Butt Welding
Extracted from BS EN 4063	

The Electric Arc

By far the most common heat source for fusion welding used in heavy industry is the electric. An electric arc can produce temperatures of $> 6000^{\circ}\text{C}$ but with extreme levels of ultra-violet, infrared and visible light. Heat is derived from the collision of electrons and ions with the base material and the electrode. An electric arc may be defined as the passage of current across an ionised gap. All gases are insulators and thus sufficient voltage, or pressure needs to be available to enable an electron to be stripped from an atom into the next (Similar to the reaction within any UV strip light). Once this conducting path or *plasma* has been created a lower voltage can normally maintain the arc though this will vary depending on the length of the arc gap. The voltage required to initiate the arc is termed the *open circuit voltage* or *OCV* requirement of the process/consumable. Voltage that maintains the arc is termed the *welding or arc voltage*.

MMA (111) TIG (141) MIG (131) MAG (135) and Submerged Arc (121) are all covered in this text in sections 10-13. Other arc welding processes within the group include MIAB or Magnetically Impelled Arc Butt Welding, (185) where an arc is formed at the closest proximity between two tubular forms. A circumferential magnetic field impels this arc around the section at ever increasing speeds. Once the leading edges are in the molten state the arc and magnetic fields are then shut down and the edges are joined under axial pressure. As all the liquid metal is extruded into a flash, the joint is made in the plastic condition and is therefore considered as solid phase.

Summary of Common Arc Welding Processes:

Process	MMA	TIG	MIG/MAG	SAW
Basic Equipment Requirements	Transformer/ Rectifier Power/power return cables Electrode holder Visor with lens Fume extraction	Transformer/ Rectifier Head assembly Hose assembly Power return cable Torch head assembly Gas cylinder Gas hoses Gas regulators Gas flow meter Visor with lens Fume extraction	Transformer/ Rectifier Head assembly Hose assembly Wire Liner Power return cable Wire feed unit Gas cylinder Gas hoses Gas regulators Gas flow meter Visor with lens Fume extraction	Transformer/ Rectifier Head assembly Hose assembly Power return cable Wire feed unit Flux hopper Flux delivery system Flux recovery system Run on/off tabs Tractor carriage Fume extraction
Arc Striking	The arc is struck <i>striking</i> the core wire onto the plate and withdrawing	<i>Scratch Start</i> (Low quality) <i>H/F or Lift Arc</i> for (High quality)	Wire contact is made by the advancement of the wire by the mechanical drive	Wire contact is made by the advancement of the wire by the mechanical drive
Arc and weld shielding	Gas for the arc and slag for weld is derived from flux	Cylinder fed inert gas shield for Arc & Weld	Cylinder fed inert /active gas shield for arc & weld	Gas for arc and slag for the weld is derived from granular flux
Weld Refining and Cleaning	Compounds and cleaning agents within the flux	Very clean, high quality drawn wire	Very clean, high quality drawn wire	Compounds within flux + higher quality wire than MMA
Process Variable Parameters	OCV Amperage Polarity AC/DC +/-ve Full electrode specification Electrode Ø Electrode pre-use baking treatments/ specified holding conditions Speed of travel	Amperage Polarity (DC -ve for steels) (AC for Aluminium) Inert gas type Gas flow rate Tungsten type Tungsten Ø Wire type Wire Ø Speed of travel	OCV Arc voltage Amperage/WFS Polarity DC +ve Gas type Gas flow rate Inductance Electrode wire type Electrode wire Ø Tip/drive roller sizes Speed of travel	OCV Arc voltage Amperage/WFS Polarity AC/DC +/-ve Electrode stick-out Flux type Flux mesh-size Electrode wire type Electrode wire Ø Wire/flux specification Speed of travel
Consumables	Short flux coated electrodes	High quality drawn wire + inert gas	High quality drawn wire + inert/active gas	High quality drawn wire + granular flux
2 x Typical Imperfections	Arc strikes Slag inclusions	Tungsten inclusions Crater pipes	Lack of fusion Porosity	Shrinkage cavities Solidification cracks
2 x General Advantages	Shop and site use Electrodes range	High quality welds Low H ₂ content	High productivity Easily Automated	Low weld-metal costs No visible arc light
2 x General Disadvantages	High skill factor Low productivity	Available wires High Ozone level	Available wires High Ozone levels	Penetration control Arc blow
Positional Capabilities	All positional, but very dependant on consumable types	All positional	Dip: All positional Spray: Flat only Pulse: All Positional	Flat only, but may be adapted for welding H/V butt welds

2) Electrical Resistance

The heat generated by electrical resistance between 2 surfaces is used to produce > 95% of all welds made in engineering, mainly in the resistance spot welding process.

2	RESISTANCE WELDING
21	Spot welding
22	Seam welding
23	Projection welding
24	Flash welding
25	Resistance butt welding
29	Other resistance welding processes

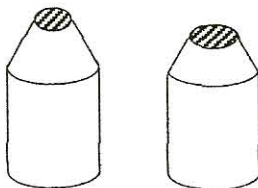
The **basic** procedural parameters for the Spot or Seam Resistance Welding process are:

- a) **Pressure** of the electrodes on material surface
- b) **Amperage** generally based on material type and thickness
- c) **Time** independent times for amperage and pressure

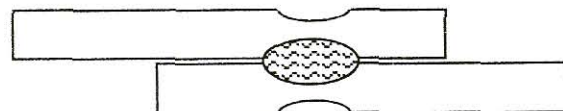
It is the most common heating method used for the spot welding of sheet materials particularly in the automotive industry and the fabrication of domestic products such as cases for washing machines, dishwashers, cookers etc. It finds little service in the fabrication of heavier section though the flash butt welding process (24) it serves as a welding process in the manufacture of longitudinally seamed pipe and also to join lengths of rolled railway lines in the mill prior to dispatch to the site where they are joined into continuous rail lengths by another welding processes described in group 7

The main inspection points of the conventional electrical resistance welding process include electrode chemical composition, as this plays a critical part in the balance of reducing wear and maximising conduction. Pure copper is a very soft metal and will wear very easily, though alloying increases hardness it greatly reduces the conductivity. As the electrode tip begins to wear the area of contact also increases which also has a marked effect on the welding cycle and the shape and effectiveness of the final weld. If conditions are incorrect then a large crater may be produced in the surface of the sheet, which will generally give cause for rejection. Most equipment is of DC output, but some AC equipment is available. It is mainly used to weld low carbon sheet steels though it is possible to weld some non-ferrous alloys including aluminium with this process, though much higher currents are needed due to the conductivity of aluminium and its alloys.

The effect of tip wear upon surface contact area of electrodes.



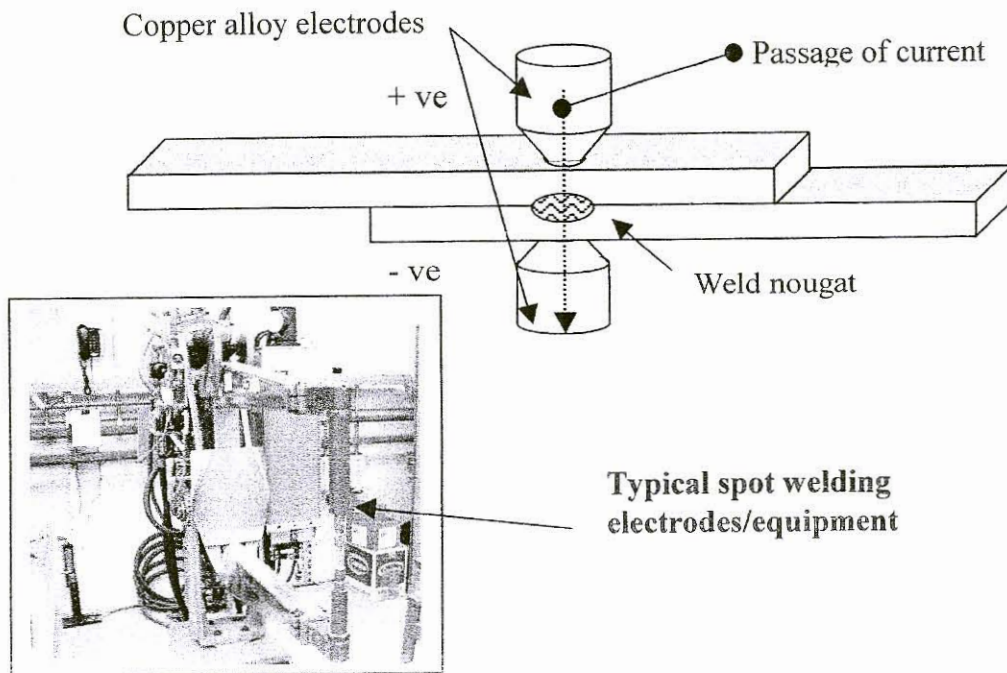
The effect of incorrect settings, increased surface contact area and/or poor fit up etc.



Spot and Seam Welding

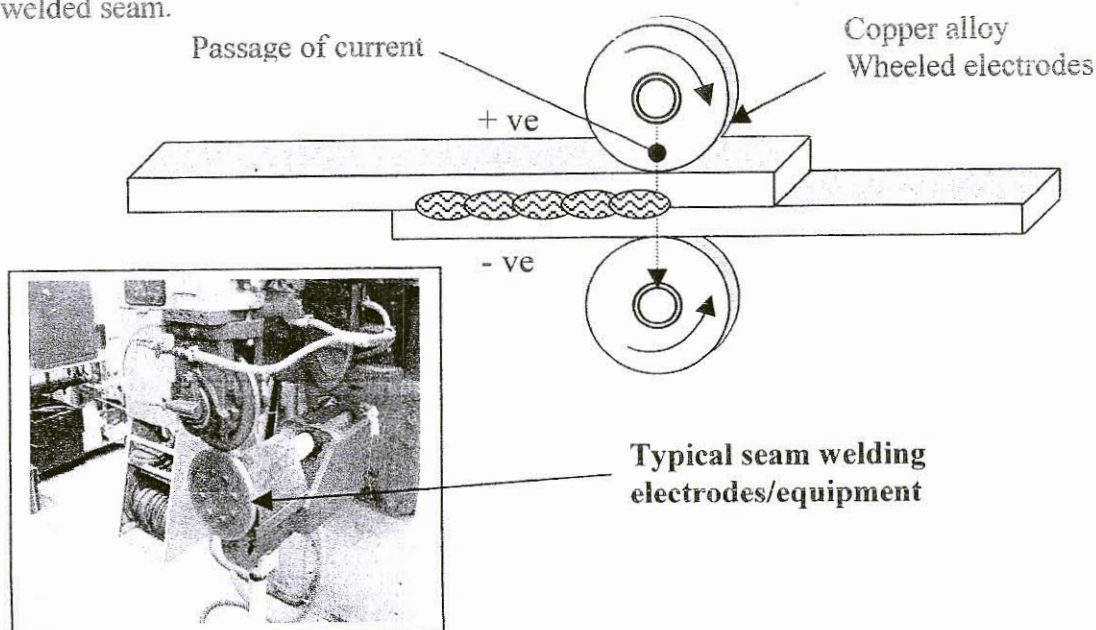
For spot or seam welding the base metals need to be in the lap joint configuration.

Spot Welding (21) Using the Resistance welding process



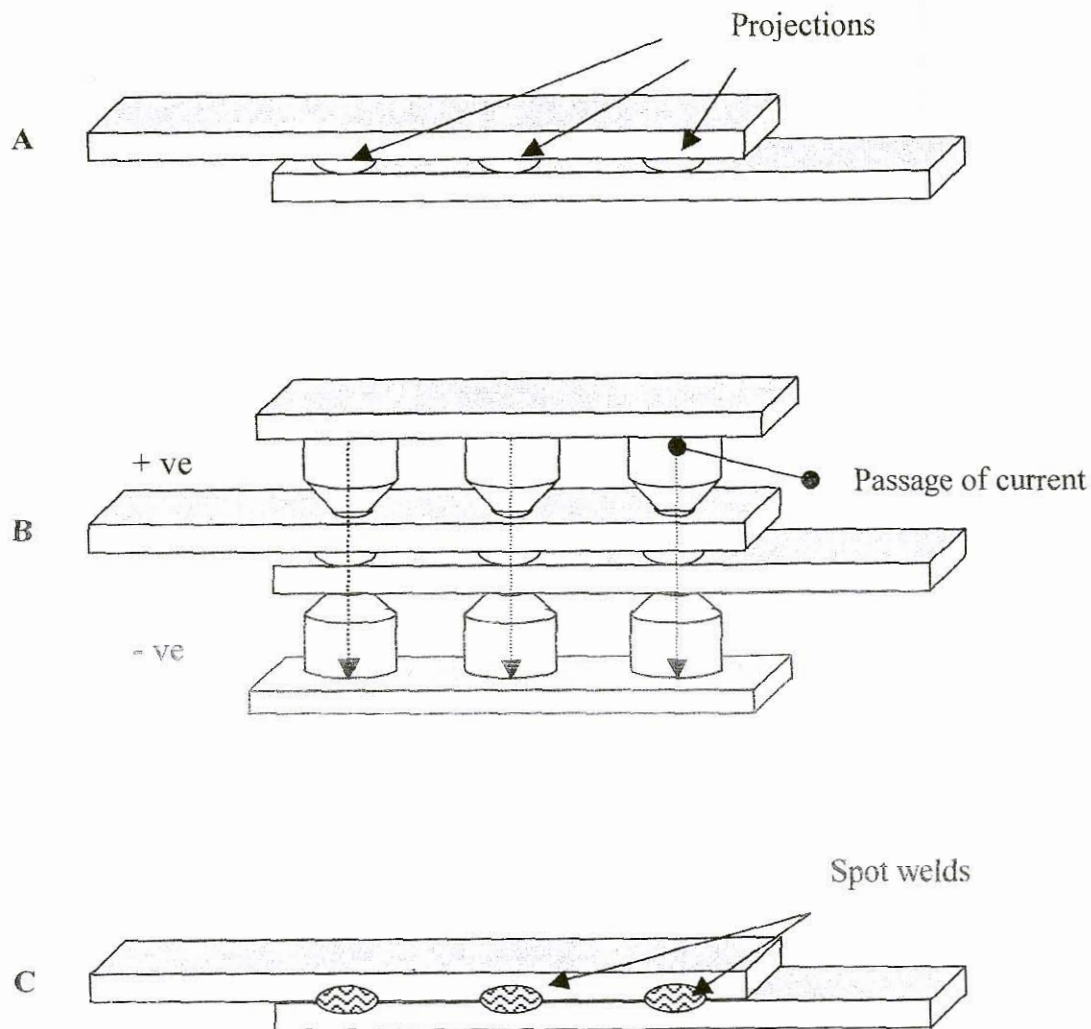
Seam Welding (22) Using the Resistance welding process

In seam welding wheeled electrodes make a series of overlapping spot welds creating a welded seam.



Projection Welding (23)

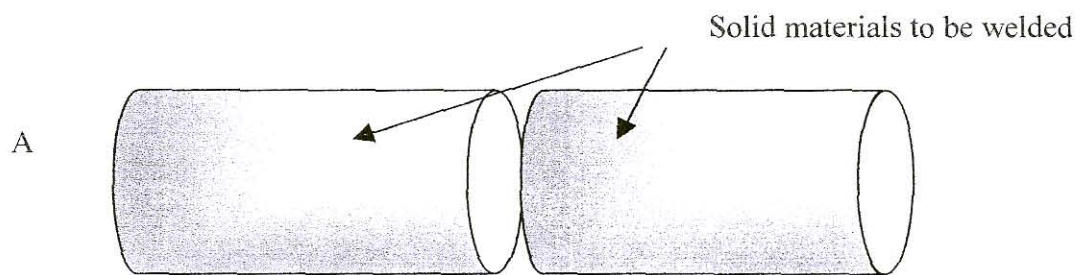
In projection welding the contact is made from projections formed between one of the items to be welded. (A) A platen of electrodes is applied from both sides directly above the projections. (B) These projections collapse from a combination of the heat generated and the applied pressure and spot welds are formed directly beneath. (C)



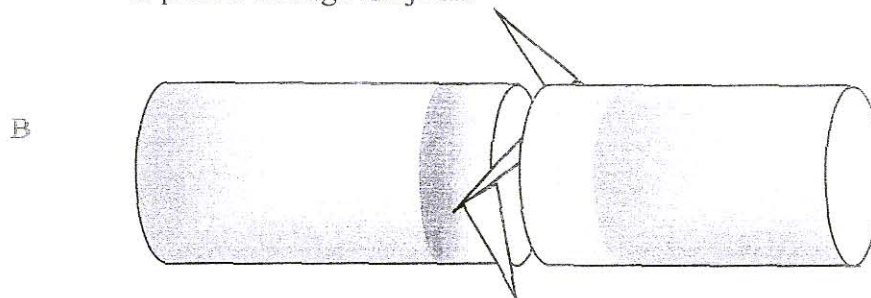
It should be noted that other welding processes may be used to produce spot welds i.e. MIG welding equipment often has a spot welding timer on the panel and spot welding may be easily carried out with the use of a spacer attachment.

Flash Butt Welding (24/25)

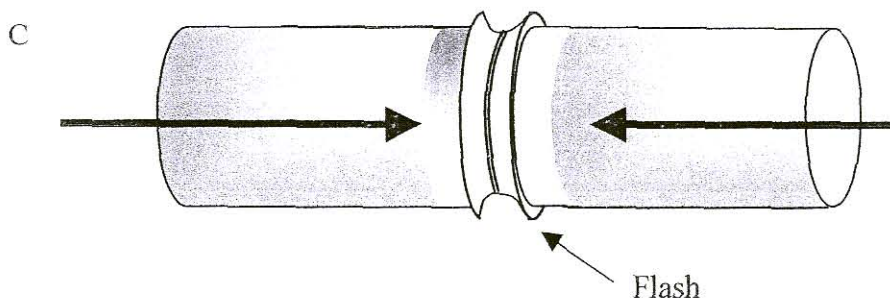
In Flash and Resistance butt-welding processes modifications of the basic resistance welding process have allowed the welding of butt joints. An important distinction is that the conventional resistance spot welding process is a fusion welding process as metal is joined from the molten state. In flash butt welding the resistance caused between 2 surfaces form a molten edge, however the pressure employed will force this molten metal to the outside of the joint causing a flash to be produced leaving the material below this to be joined in the plastic condition, hence this process is considered to be of the solid state group. This process is also used in strip steels mills to join lengths of strip.



The faces are placed in close proximity and a high current and voltage is passed through the joint.



The joint faces are moved slightly apart causing a gap to occur and creating an arc. Resistance heating in the arc melts the leading edges of the joint.



The current is switched off and axial pressure applied.
The materials are joined in the plastic condition and a flash is produced.

3) Combustion of Gases

Oxygen & acetylene will combust to produce a flame temperature of 3,200 °C. Other fuel gases may be used for oxy-fuel gas cutting, as this requires a lower temperature. The *intensity of heat* in a chemical flame is not as high as other heating methods and as such a longer time needs to be spent applying the heat to bring a metal to its melting point as heat is dissipated by conduction, convection and radiation

3	GAS WELDING
31	Oxy-fuel gas welding
311	Oxy-acetylene welding
32	Air fuel gas welding

The gas welding process is not as widely used these days though it is a handy standby as there is not much that cannot be done with this process in the hands of a good craftsman.

4) Welding with Pressure

4	WELDING WITH PRESSURE
41	Ultrasonic welding
42	Friction welding
44	Welding by high mechanical energy
45	Diffusion welding
47	Gas pressure welding
48	Cold pressure welding

Friction (42)

A most useful Welding Process in this group is Friction Welding where heat is generated by moving the two parts to be welded together to generate heat, then applying pressure to weld components together. The joint is made while the material faces remain in the **plastic condition** and is thus a solid phase welding process.

Generally one of the 2 components to be welded is rotated in a chuck and the other is held in the same axis in a stock. The 2 surfaces are brought into contact and friction is generated between the 2 faces. This caused heat to be produced which eventually brings the faces into their plastic condition. The rotation is arrested and an axial load is applied to the components forcing any liquid out of the joint to form a flash. The faces are now joined in the plastic condition. A variation of this process is **Inertia Welding (44)** where a flywheel is left in motion as the axial load is applied. As there is no liquid phase in the **weld metal** this process enables a great many materials to be joined together including aluminium to steels, ceramics to metals etc. There are a great many variations on the process with **Friction Stir Welding** at the cutting edge of this technology.

Diffusion Bonding (45) is also a solid phase process where parts to be welded are loaded in compression and heated to beneath their melting point when plastic movement takes place. A perfect surface is created between the bonding surfaces, with *diffusion* of atoms causing molecular bridges. This process can be used to create some very complex fabrications, which would be impossible to make by other means.

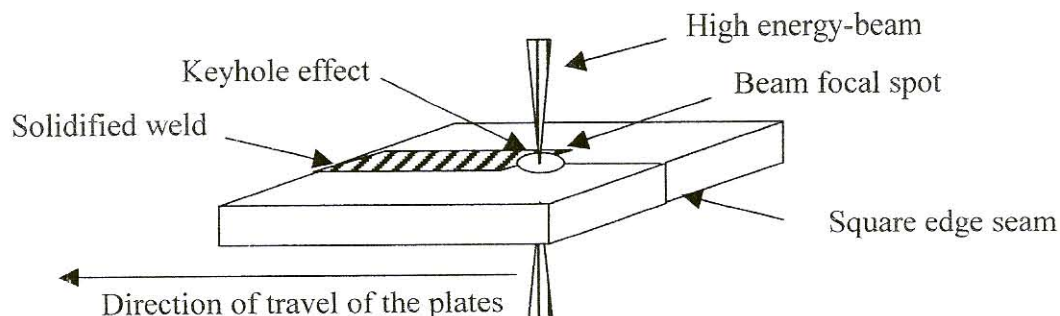
5) Beam Welding

High-energy beam processes are used in specialist applications such as aerospace, where any high cost of the equipment is outweighed by the implications of failure in any component. These processes utilise a focal spot of high energy to punch a hole through the welded seam producing a **keyhole**, vaporising the metal. This resultant vapour cloud surrounds the beam keeping the keyhole patent. The seam is generally traversed beneath the beam and solidification takes place behind the moving keyhole. Butt welds are always made with a **square edge** preparation and weld fit up is **extremely** critical.

5	BEAM WELDING
51	Electron beam welding
511	Electron beam welding in a vacuum
512	Electron beam welding out of vacuum
52	Laser welding
521	Solid state LASER welding
522	Gas LASER welding

In Vacuum Electron Beam (511) has the highest penetrating power of these processes and can weld >100mm thick steel in a square edge butt. It is commonly used in the aerospace industry for the welding of titanium alloy components, where protection from oxidation is critical. It may also be used to weld high carbon and difficult to weld steels by practically removing the risk of hydrogen associated cracking. *Out of vacuum EB (512)* reduces operating costs, but loses the high degree of protection from oxidation and reduces the amount of penetration through divergence effects in the beam focal spot.

Laser (52) (Light Amplifications through Stimulated Emissions of Radiation) light has been used for welding/cutting for many years now, though the CO₂ lasers (522) initially used had a major drawback in that the beam required manipulation by a series of mirrors that restricted wider use of the process. With the development of the NdYAG Laser (A crystal containing neodymium in yttrium aluminium and garnet) (521) a frequency of laser light is produced that can be passed through a fibre optic making this system of welding extremely flexible. High-energy beam welding allows very fast welding speeds with a narrow HAZ and producing a very minimal amount of distortion.



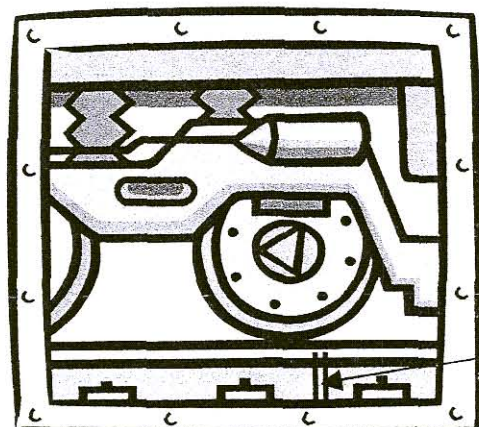
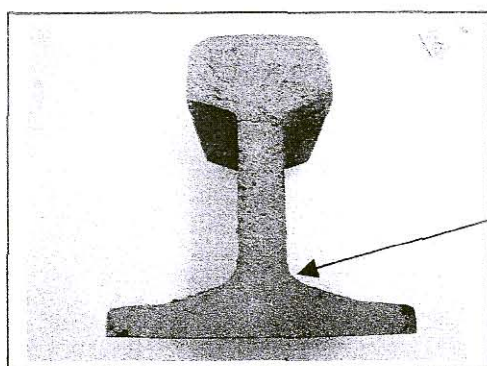
7) Other Welding Processes

In this category of welding processes all those processes that cannot be classified within the other groups are given here.

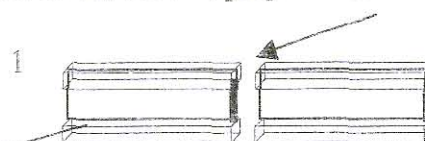
7	OTHER WELDING PROCESSES
71	Alumino-thermic welding (Thermite)
72	Electro-slag welding
73	Electro-gas welding
74	Induction welding
75	Light radiation welding
77	Percussion welding
78	Stud welding

Alumino-Thermic Welding (71)

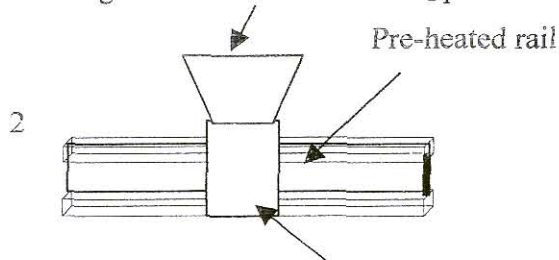
This is generally used for on site welding of railway line. A crucible is charged with aluminium and iron oxide and heated. The mixture is then ignited and an exothermic chemical reaction takes place where the aluminium reacts with the iron oxide resulting in the formation of aluminium oxide + iron + heat. The temperature reached is around 2,500 ° C where the iron is molten but the aluminium oxide (the ceramic alumina) remains as a solid. The molten iron is discharged into a ceramic mould prepared around the weld area, where it meets the pre-heated rail and becomes fused. After the weld has solidified and cooled the mould is removed and the rail is dressed.



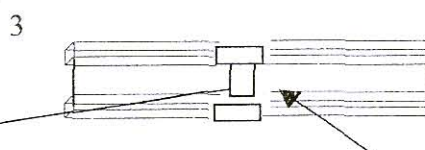
The rail is cut and prepared for welding



The charged crucible of Al + Fe O₂ powder



A shaped ceramic or firebrick mould

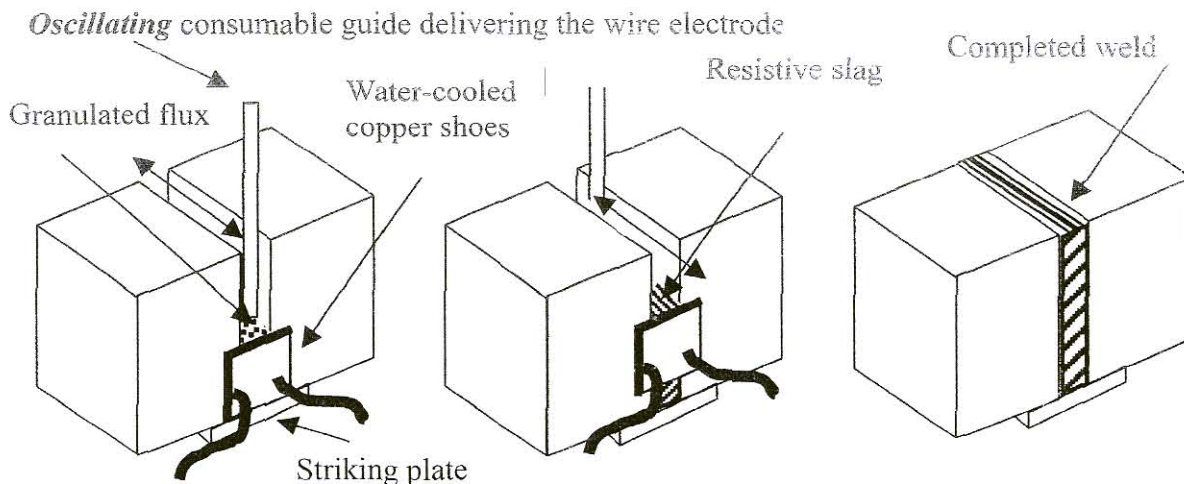


The mould is removed and the rail is dressed

The Electro-Slag Welding (72)

This is a welding process where a molten slag of high resistivity is used to aid weld metal deposition. The process is mainly used for thick section vertical up butt welds. First a highly resistive granulated flux is placed in the bottom of the joint on the striking plate and a set of water-cooled copper shoes are attached to each side of the joint. An arc is struck which melts the flux producing a molten slag that is kept from flowing out of the joint by the copper shoes. The arc is extinguished and the wire now feeds into the molten flux bath, which is highly resistive. The heat generated is sufficient to melt both the wire and the sidewalls of the welded joint. The wire and welding head may be traversed (*oscillated*) backwards and forward along the joint line to produce an even fusion rate. Many wires may be used when welding thicker sections. Welding takes place and both the weld and copper shoes rise to the top of the seam. On completion the shoes are removed and the weld is cleaned. The high heat energy of this process (typically around 50 – 60 kJ/mm) results in a large and brittle grain structure. If good toughness is required in the joint then a complete *normalise* heat treatment must be done to the steel. This is an expensive heat treatment but it is often the case that the high cost of heat treatment is very much offset by the speed of welding thick section vertical butt welds.

A further development of this process is **Consumable Guide** Electro-Slag welding (**Shown Below**) where the welding head remains stationary and the wire is fed down through an oscillating guide, which also becomes consumed in the weld. This increases the range of chemical compositions of weld metal available to the Welding Engineer, as the resultant weld is comprised of the wire, the base metal and the guide. The Electro-Slag principle is often applied to strip cladding processes.



1) The copper shoes are attached and the granulated flux is placed in the joint, and the arc is struck. The flux melts and the arc is extinguished. The wire now feeds into the resistive slag

2) As the weld continues the weld metal rises and copper shoes must also rise up the joint. The wire may also be traversed. The weld metal solidifies beneath the slag

3) The finished weld

9) Brazing, Soldering and Braze/Bronze Welding

The soldering, brazing and braze welding processes are not classified as fusion processes as only partial or surface fusion takes place during the process, however there are a number of elements that require explanation as follows:

9	BRAZING, SOLDERING & BRAZE WELDING
91	Brazing
912	Flame brazing
913	Furnace brazing
914	Dip brazing
93	Other brazing processes
94	Soldering
942	Flame soldering
952	Soldering with soldering iron
96	Other soldering processes
97	Braze welding
971	Gas braze welding
972	Arc braze welding

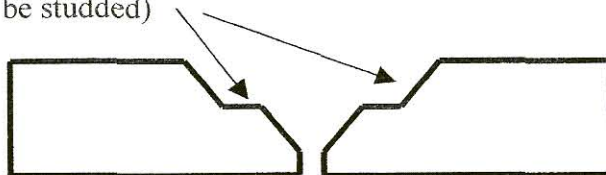
Brazing (93) In the correct use of the term Brazing 2 elements need to be satisfied:

- The use of a filler material with a solidification temperature $> 500^{\circ}\text{C}$
- A joint design using capillary action between 2 faces as the prime method of joining

Soldering (94) Conditions of this process are generally the same as for Brazing but with the solidification of the filler alloy being $< 500^{\circ}\text{C}$. This process is most commonly used in the joining of copper electrical components and wire connections.

Braze welding (97) This process may use similar filler alloy materials as when brazing. The fundamental difference between them is that the joint design does not rely alone on capillary action **between the 2 surfaces** to be joined, and a butt or fillet **weld** is generally produced in the joint area. An example of where this is used is in the braze of a cast iron butt joint where in order to maximise the *joint surface area* the preparation may appear like the following

(This area may also be studded)



All group 9 processes rely primarily on a surface adhesion of the filler alloy from within the grain boundaries of the base metal to produce a sound joint though a degree of finite surface alloying may also occur. The success and thus the main inspection points of this group of processes are mostly concentrated around the *joint preparation* and *cleanliness*.

WIS 5 Section 9 Exercises:

- 1) Complete the 4 basic requirements to be satisfied for fusion welding processes?

1. A Heat source (Of high enough intensity to melt the base metals)

2. _____

3. _____

4. _____

- 2) Complete the basic parameters to be considered in resistance spot welding?

1. Current

2. _____

3. _____

- 3) List 4 other elements to be considered when using the Electro Slag process?

1. Joint type

2. _____

3. _____

4. _____

5. _____

- 4) Describe the main differences between Soldering Brazing and Braze Welding?

WIS 5 Welding Inspection

Section 10

Manual Metal Arc Welding (MMA SMAW)

Arc Characteristic for MMA & TIG

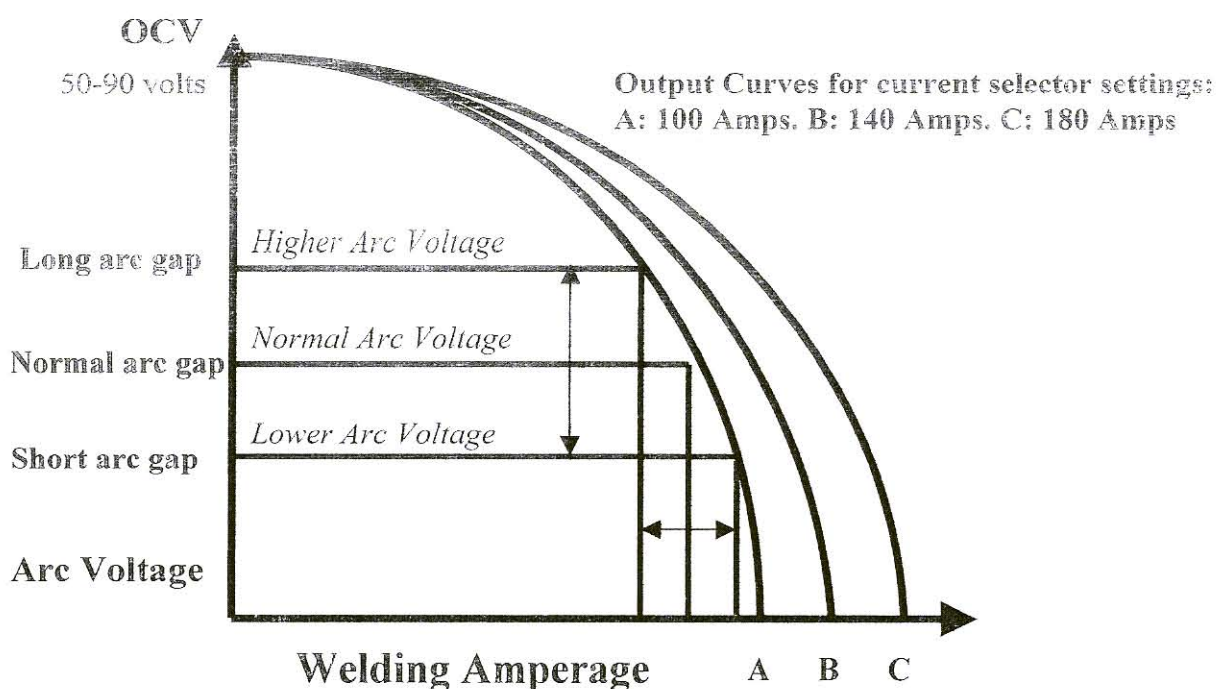
In MMA & manual TIG welding the arc length is controlled solely by the welder. Whilst an experienced and highly skilled welder can keep the arc length at a fairly constant length there will always be some variation.

When the arc length is increased, the voltage or pressure required to maintain the arc will also need to increase. This would proportionally reduce the current in a normal electrical circuit where the supplied voltage is proportional to a drop in current. Thus a way needs to be found of reducing this large drop in current during high variations in arc voltage.

This is achieved by the use of electrical components within the equipment the effects of which can be represented graphically by sets of operating curves, as shown below.

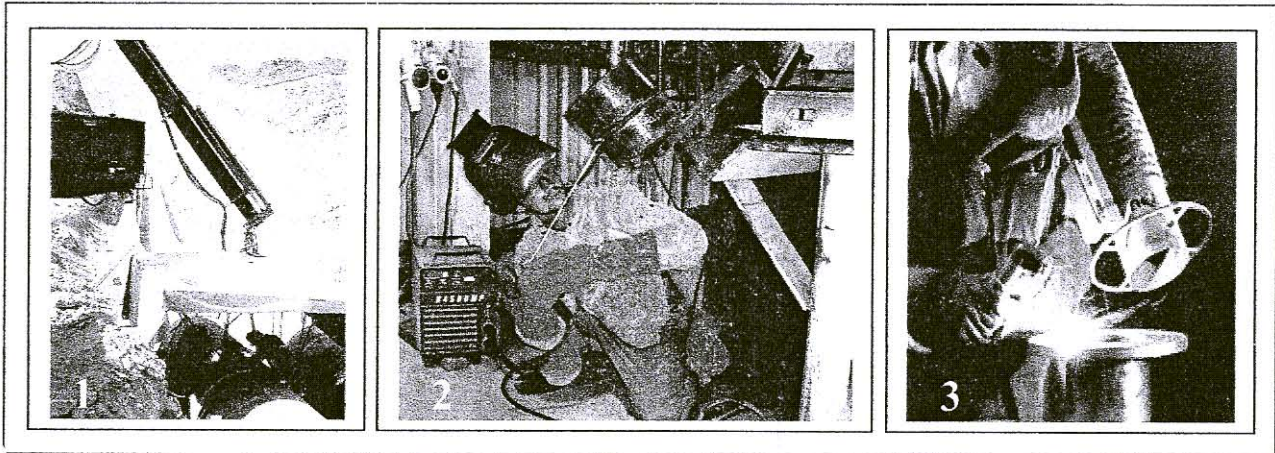
The graphs below represent a typical relationship between volts and amps showing the effect of variation in the arc gap and voltage.

A Constant Current Volt/Amp Characteristic



A large variation in voltage = A smaller variation in amperage

Manual Metal Arc Welding



MMA is a welding process that was first developed in the late 19th century using bare wire electrodes. It has found very wide use in both site and workshop applications.

Definitions

MMA Manual Metal Arc Welding. (UK) 111

SMAW Shielded Metal Arc Welding. (USA)

Introduction:

MMA is simple process in terms of equipment and consumables, using short flux covered electrodes. The electrode is secured in the electrode holder and the leads for this and the power return cable are placed in the + or – electrical ports as required. The process demands a **high level of skill** from the welder to obtain consistent high quality welds but is widely used in industry mainly because of the range of available consumables, its positional capabilities and adaptability to **site work**. (Photograph 1)

The electrode core wire is often of very low quality as refining elements are easily added to the flux coating that can produce high quality weld metal relatively cheaply.

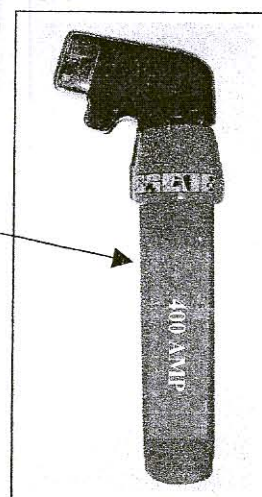
The arc is struck by striking the electrode onto the surface of the plate and withdrawing it a small distance, as you would strike a match. The arc should be struck in the direct area of the weld preparation avoiding arc strikes or stray flash on the plate material. Care should also be taken to maintain a short and constant arc length and speed of travel.

Photograph 2 shows a trainee dressed in the correct safety clothing, whilst photograph 3 indicates the level of process-produced fume and the use of a flexible hose extraction system. Little has changed with the basic principles of the process since it was developed but improvements in consumable/flux technologies occur on a very regular basis.

Manual Metal Arc Welding Basic Equipment Requirements



- 1) **Power source Transformer/Rectifier.** (Constant current type)
- 2) **Holding oven.** (Temperature up to 150 °C)
- 3) **Inverter power source**
- 4) **Electrode holder**
- 5) **Power cable**
- 6) **Welding visor with correct filter glass rating**
- 7) **Power return cable**
- 8) **Electrodes**
- 9) **Electrode oven.** (Bakes up to 350 °C)
- 10) **Control panel.** (On\Off/Amperage/Polarity/OCV)



Variable Parameters

1) Voltage

The **OCV** (Open Circuit Voltage) is the voltage required to initiate or re-ignite the electric arc and will change with the type of electrode being used. Most basic coated electrodes require an OCV of 70 – 90 volts while most rutile electrodes require 50 volts.

The **Arc Voltage** of a welding process is measured as close to the arc as possible. It is only variable in MMA with changes in arc length and/or poor electrical connections.

2) Current & Polarity

The type and value of current used will be determined by the choice of electrode classification, electrode diameter, material type and thickness and the welding position.

Electrode polarity is generally determined by the operation i.e. surfacing/joining and the type of electrode or electrode coating being used. Most surfacing and non-ferrous alloys require DC – for correct deposition, although there are exceptions to this rule. Electrode burn off rates will vary with AC or DC + or – depending on the coating type and the choice of polarity will also affect heat balance of the electric arc. Always follow the approved welding procedure or in its absence the manufacturers advice.

Important Inspection Points/Checks when MMA Welding

1) The Welding Equipment

A visual check should be made to ensure the welding equipment is in good condition.

2) The Electrode

Checks should be made to ensure that the correct specification of electrode is being used, that the electrode is of the correct diameter and that the flux coating is in good condition. A check should be made to ensure that any basic coated electrode being used has been pre-baked to that specified in the welding procedure. A general pre-use treatment for basic coated electrodes would typically be:

- a) **Baked at 350 °C for 1 hour**
- b) **Held in holding ovens at between 120 -150 °C max**
- c) **Issued to the welder in a heated quiver. (Normally around 70 °C)**

Vacuum pack pre-baked electrodes do not need to undergo this pre-baking treatment but only if the vacuum seal is observed to be broken at the point of opening by the inspector. The date and time that the carton and vacuum seal was broken should always be **recorded** by the responsible welding inspector. Users should always follow the manufacturers advice and instructions to maintain the hydrogen level specified on electrode cartons. Cellulosic and rutile electrodes do not require this pre-use treatment but should be stored in a dry condition. Rutile electrodes may require “drying only when damp” and should therefore be treated as damp unless evidence dictates otherwise and dried (**not baked**) at a specified temperature.

3) OCV

A check should be made to ensure that the equipment can produce the OCV required by the consumable and that any voltage selector has been moved to the correct position.

4) Current & Polarity

A check should be made to ensure the current type and range is as detailed on the WPS.

5) Other Variable Welding Parameters

Checks should be made for correct angle of electrode, arc gap distance, speed of travel and all other essential variables of the process given on the approved welding procedure.

6) Safety Checks

Checks should be made on the current carrying capacity, or duty cycle of equipment and that all electrical insulation is sound.

A check should also be made that correct eye protection is being used when welding and chipping slag and that an efficient extraction system is in use to avoid over exposure to toxic fumes and gases.

A check should always be made to ensure that the welder is qualified to weld the procedure being employed.

Typical Welding Imperfections

- 1) **Slag inclusions** caused by poor welding technique or insufficient inter-run cleaning.
- 2) **Porosity** from using damp or damaged electrodes or when welding contaminated or unclean material.
- 3) **Lack of root fusion or penetration** caused by in-correct settings of amps, root gap or face.
- 4) **Undercut** caused by too high amperage for the position or by a poor welding technique e.g. travel speed too fast or too slow, arc length (therefore voltage) variations particularly during excessive weaving.
- 5) **Arc strikes** caused by incorrect arc striking procedure, or lack of skill. These may be also caused by incorrectly fitted/secured power return lead clamps.
- 6) **Hydrogen cracks** caused by the use of incorrect electrode type or incorrect baking procedure and/or control of basic coated electrodes.

Summary of MMA/SMAW:

xxx

Equipment requirements

- 1) A Transformer/Rectifier, generator, inverter. (Constant amperage type)
- 2) A power and power return cable
- 3) Electrode holder
- 4) Electrode
- 5) Correct visor/glass, all safety clothing and good extraction

Parameters & Inspection Points

- | | |
|------------------------------|-------------------------------------|
| 1) Amperage | 2) Open Circuit Voltage. (OCV) |
| 3) AC/DC & Polarity | 4) Speed of travel |
| 5) Electrode type & diameter | 6) Duty cycles |
| 7) Electrode condition | 8) Connections |
| 9) Insulation/extraction | 10) Any special electrode treatment |

Typical Welding Imperfections

- | | |
|---------------------------------------|---|
| 1) Slag inclusions | 2) Porosity |
| 3) Lack of root fusion or penetration | 4) Undercut |
| 5) Arc strikes | 6) H ₂ Cracks. (Electrode treatment) |

Advantages & Disadvantages

Advantages

- 1) Field or shop use
- 2) Range of consumables
- 3) All positional
- 4) Very portable
- 5) Simple equipment

Disadvantages

- 1) High skill factor required
- 2) Arc strikes/Slag inclusions
- 3) * Low Operating Factor
- 4) High level of generated fumes
- 5) Hydrogen control

* **Operating Factor:** (O/F) The percentage (%) of "Arc On Time" in a given time span.

When compared with semi automatic welding processes the MMA welding process has a low O/F of approximately 30% Manual semi automatic MIG/MAG O/F is in the region 60% with fully automated MIG/MAG in the region of 90% O/F. A welding process **Operating Factor** can be directly linked to **productivity**.

Operating Factor should **not to be confused** with the term **Duty Cycle**, which is a safety value given as the % of time a conductor can carry a current and is given as a specific current at **60%** and **100%** of 10 minutes i.e. 350amps 60% and 300amps 100%

WIS 5 Section 10 Exercises:

- 1) Complete the basic equipment requirements for the MMA processes?

1. A Transformer/Rectifier. (Constant amperage type)

2. _____
3. _____
4. _____
5. _____

- 2) List 9 further parameter inspection points of the MMA welding process?

- | | |
|--------------------|-----------|
| 1. <u>Amperage</u> | 2. _____ |
| 3. _____ | 4. _____ |
| 5. _____ | 6. _____ |
| 7. _____ | 8. _____ |
| 9. _____ | 10. _____ |

- 3) List 5 further typical imperfections that may be found in MMA welds?

- | | |
|---------------------------|----------|
| 1. <u>Slag Inclusions</u> | 2. _____ |
| 3. _____ | 4. _____ |
| 5. _____ | 6. _____ |

- 4) List 2 further advantages and disadvantages of the MMA welding process?

Advantages

Disadvantages

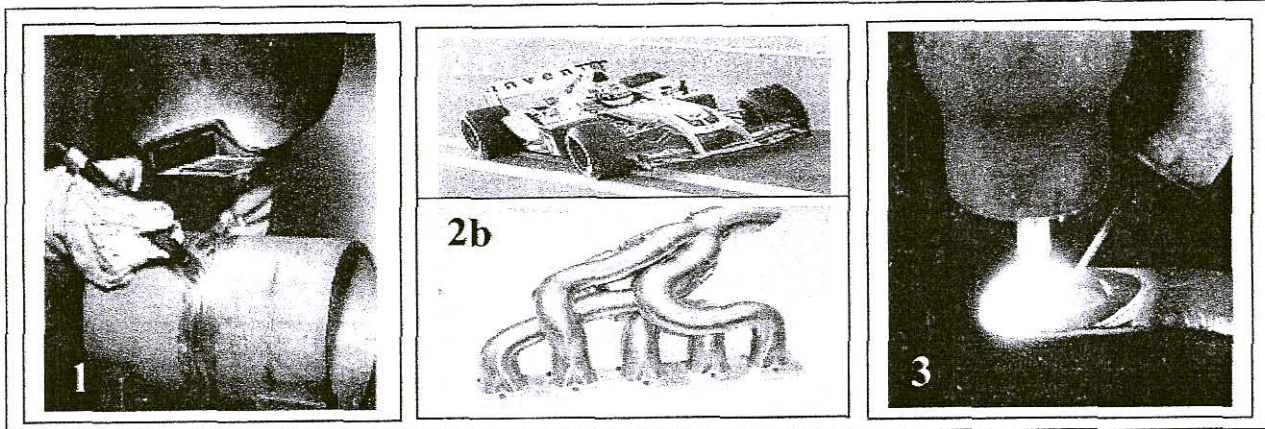
- | | |
|-----------------------------|--------------------------------------|
| 1. <u>Field or Shop use</u> | 1. <u>High Skill factor required</u> |
| 2. _____ | 2. _____ |
| 3. _____ | 3. _____ |

WIS 5 Welding Inspection

Section 11

Tungsten Inert Gas Welding (TIG GTAW)

Tungsten Inert Gas Welding:



TIG welding was first developed in the USA during the 2nd world war for welding aluminium alloys. As helium was used as the gas the process was known as Heliarc.

Definitions

TIG Tungsten Inert Gas Welding. (UK) 141

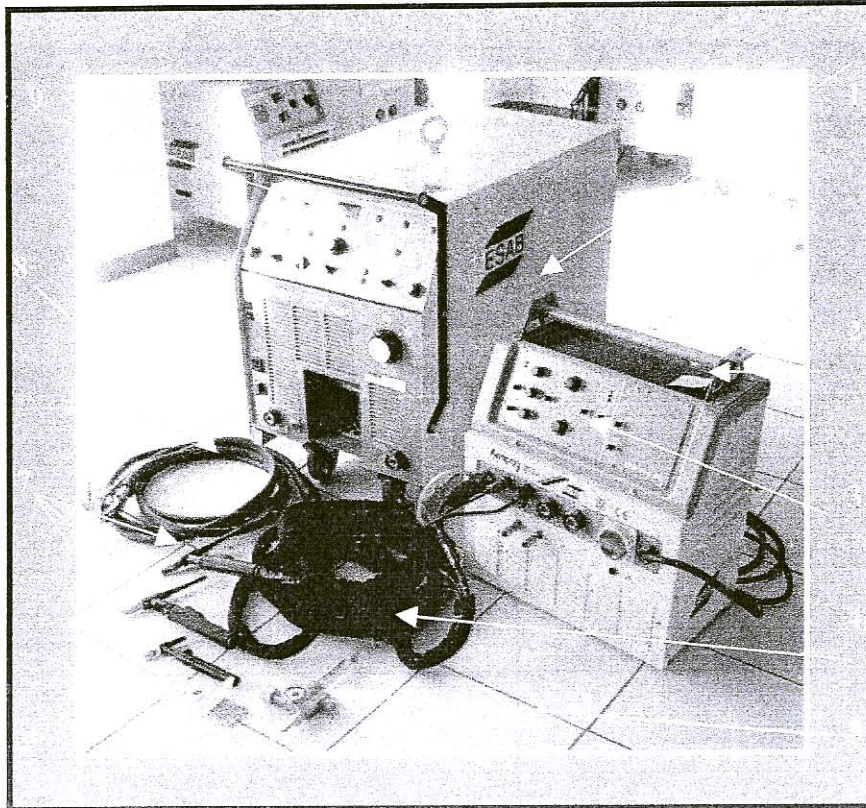
GTAW Gas Tungsten Arc Welding. (USA)

Introduction:

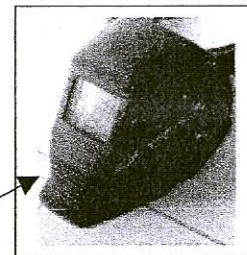
TIG welding is a process that requires a very high level of welder skill, as can be gauged in the apparent concentration of the welder above. (Photo 1) It is also a process synonymous with *high quality* welds and is used to weld many parts of a *Formula 1* racing car (Photo 2a) including the *Inconel* exhaust system (Photo 2b) It is generally considered a comparatively slow process but with the development of *Hot-Wire TIG* (Photo 3) very high quality production welds can be made with deposition rates *rivalling* those found in SAW. TIG may also be used in narrow gap preparations.

The arc may be struck by using a number of methods but in cheaper equipment the arc is struck *Scratch start* in a similar way to MMA welding. This can easily cause contamination of the tungsten and weld metal and to avoid this **high frequency** arc ignition is often used in most equipment to initiate the arc, however high frequency may cause interference with hi-tech electrical equipment and computer systems. To overcome this *Lift arc* has been developed where the electrode is touched onto the plate and is withdrawn slightly. An arc is produced with very low amperage, which is increased to full amperage as the electrode is extended to the normal arc length. In contrast with other arc processes the filler wire is added directly into the pool separately by the welder, which requires a *very high level of hand dexterity* and artisan craft skill from the welder. **Orbital TIG** welding is a mechanised adaptation of the process for welding tubes/pipes. TIG is a far more complex process than MMA with more variable parameters to adjust and parts to check and therefore more inspection points for the inspector to meet.

Tungsten Inert Gas Welding Basic Equipment Requirements

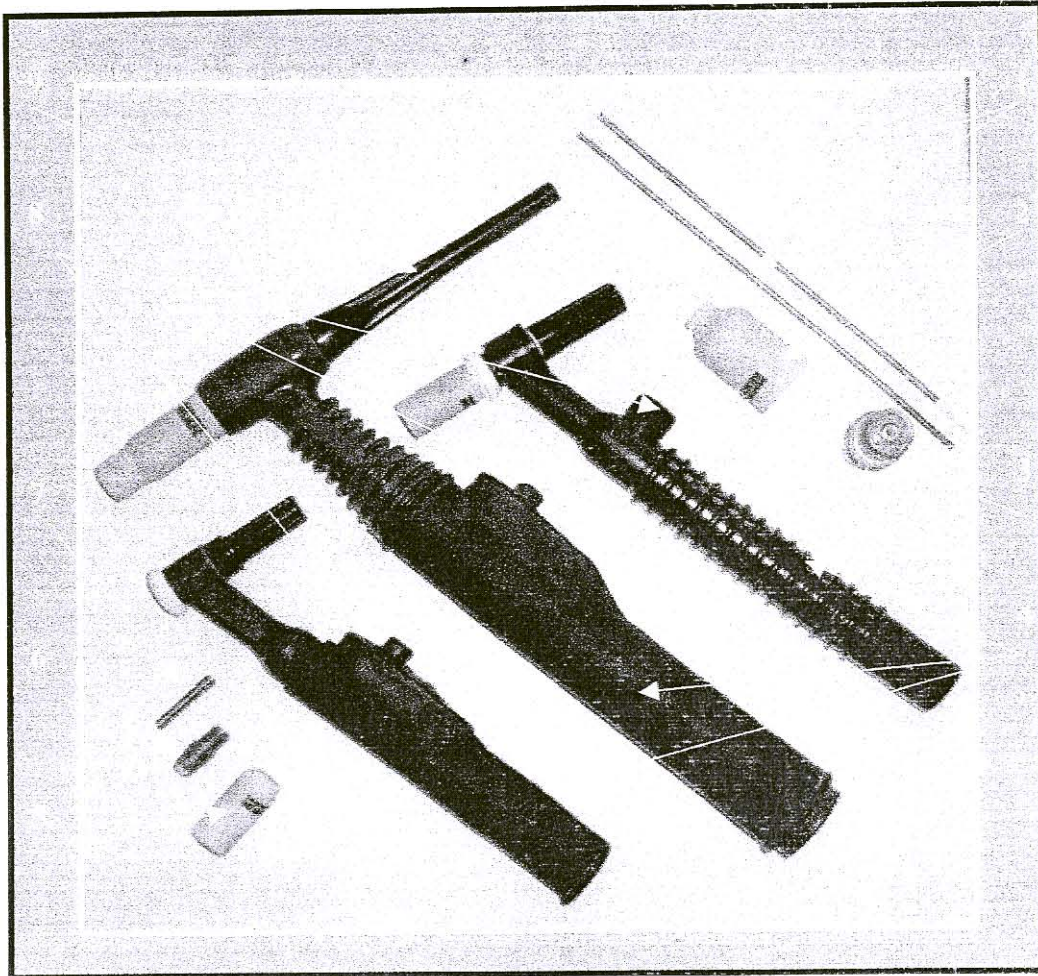


- 1) Power source. Transformer/Rectifier. (Constant Amperage type)
- 2) Inverter power source
- 3) Power control panel
- 4) Power cable hose
- 5) Gas flow-meter
- 6) Tungsten electrodes
- 7) Torch assemblies
- 8) Power return cable
- 9) Power Control panel. (Amperage & polarity)
- 10) Welding visor with correct filter glass rating

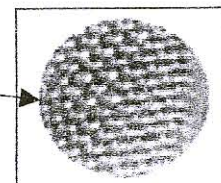
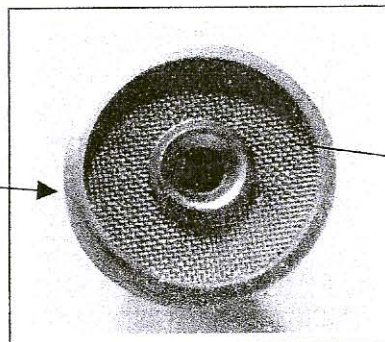


A regulated inert gas supply is also required for this process

The TIG Torch Head Assembly



- 1) Tungsten electrodes
- 2) Spare ceramic shield
- 3) Gas lens
- 4) Torch body
- 5) Spare ceramic shield
- 6) Gas diffuser
- 7) Split copper collet. (For securing the tungsten electrode)
- 8) On/off or latching switch
- 9) Tungsten housing



Variable Parameters

1) Arc Voltage

The Arc voltage of the TIG welding process is variable by the type of gas being used, and changes in arc length as in MMA and soundness of the connections.

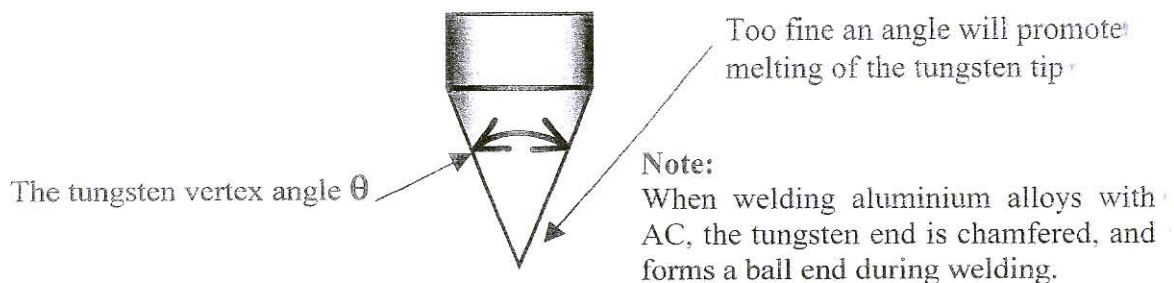
2) Current & Polarity

The current is adjusted proportionally to the diameter of the tungsten being used. The higher the level of the current, then the higher is the level of penetration and fusion that is obtained.

The polarity used for steels is **always** DC -ve as most of the heat is concentrated at the + pole in TIG welding. This is required to keep the tungsten as cool as possible during welding and maximises penetration. AC is used when welding aluminium and its alloys.

3) Tungsten type, size and vertex angle

The tungsten diameter, type of tungsten, and vertex angle, are all critical factors considered as essential variables of a welding procedure. The most common types of tungsten used are thoriated or ceriated for DC and zirconiated with AC (aluminium alloys) Available shelf sizes range from **1.6 – 10mm Ø** though 1.6 2.4 and 3.2mm Ø are more commonly used. The vertex angle of the tungsten is often a procedural parameter and therefore grinding needs to be a very controlled activity that should always be carried out on a *dedicated grinding wheel*. The vertex angle is measured as shown below.



4) Gas type and flow rate

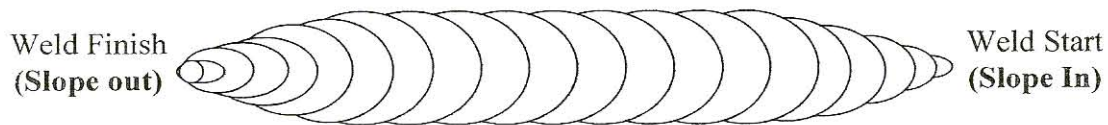
Generally 2 types of pure gases are used for TIG welding; namely **argon** and **helium**, though nitrogen is sometimes added for welding copper and hydrogen additions may be made for austenitic stainless steels (increasing welding speed). The gas flow rate is a further essential variable of the welding procedure. This will change on joint type and welding position and gas type. TIG gases are produced in purity of 99.99% and though argon is cheaper than helium and has higher density than air, it has lower ionisation potential giving a relatively *shallow penetration*. Helium is more expensive than argon and has a lower density than argon and air but with a higher ionisation potential giving *higher penetration* and a hotter arc. This means practically that due to the density factor the flow rate of helium must be increased in the down-hand position and argon increased in the overhead position for a similar joint design in order to maintain adequate gas cover of the weld zone. Argon and helium gases are often mixed to combine the useful features of each gas i.e. gas cover and penetration. The fitting of a *gas lens* is *critical* in avoiding gas turbulence in TIG.

5) Slope in and slope out

Slope in and slope out are variables available on some TIG welding equipments, which can regulate the current climb and decay. This is very beneficial in avoiding crater pipes at the end of weld runs. The slope in and slope out control may be shown on the equipment as below

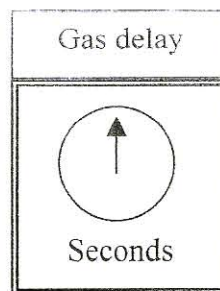


During welding it is used to control the rise and decay of the current at the start and end of a weld as shown below



6) Gas cut off delay

The gas cut off delay control delays the gas solenoid shut off time at the end of the weld and is used to give continued shielding of the solidifying and cooling weld metal at the end of a run. It is often used when welding materials that oxidise at high temperatures such as stainless and titanium alloys. It may be shown on the welding equipment as follows



7) Pulsed TIG welding variables

The pulse parameters of pulsed TIG are generally adjustable as follows

- | | |
|-----------------------------|-----------------------|
| a) Pulse background current | c) Pulse peak current |
| b) Pulse duration | d) Pulse frequency |

Important Inspection Points/Checks when TIG Welding

1) The Welding Equipment

A visual check should be made to ensure the welding equipment is in good condition.

2) The Torch Head Assembly

Check the diameter and specification of the tungsten, the required vertex angle has been correctly ground, and that a **gas lens** has been fitted. Check the tungsten protrudes the correct length from the ceramic, the ceramic is the correct type and in good condition.

3) Gas type and flow rate

Check the correct gas, or mixture and the flow rate is correct for the given joint design and position all given on the approved welding procedure. Check if a **Gas lens** is fitted.

4) Current & Polarity

Checks should be made to ensure that the type of current and polarity are correctly set, and that the current range is within that given on the procedure. These values will be controlled by the material type, thickness and diameter and type of tungsten being used.

5) Other Variable Welding Parameters

Checks should be made for correct angle of torch, arc gap distance, speed of travel and all other essential variables of the process given on the approved welding procedure.

In mechanised welding checks will need to be made on the speed of the carriage mechanism and the speed of the filler wire. Additionally when welding reactive materials checks will need to be made on purging or backing gas type and pressures.

6) Safety Checks

Checks should be made on the current carrying capacity or duty cycle of equipment and that all electrical insulation is sound. Correct extraction systems should be in use to avoid exposure to ozone and other toxic fumes.

A Check should always be made to ensure that the welder is qualified to weld the procedure being employed.

Typical Welding Imperfections

- 1) **Tungsten inclusions**, caused by a lack of welder skill, too high current setting, and/or incorrect vertex angle.
- 2) **Surface porosity**, caused by a loss of gas shield particularly when site welding, or incorrect gas flow rate for the joint design and/or welding position.
- 3) **Crater pipes**, caused by poor finish technique or incorrect use of current decay.
- 4) **Weld/root oxidation** if using insufficient gas cut-off delay or purge pressure when welding stainless steels or titanium alloys.

Summary of TIG/GTAW:

Equipment requirements

- 1) A Transformer/Rectifier. (*Constant amperage type*)
- 2) A power and power return cable. (*Of a suitable amperage rating*)
- 3) An inert shielding gas. (*Argon, helium or a mixture*)
- 4) Gas hose, flow meter and *gas regulator. (**Correct for gas type and flow rates*)
- 5) Torch (*Of a suitable amperage rating*) and Tungsten electrode (*Of correct Ø and type*)
- 6) Collet and ceramic, with gas diffuser and gas lens. (*Of correct size for the electrode Ø*)
- 7) Method of arc ignition. (*H/F, Lift Arc or scratch start*)
- 8) Correct visor/glass, all safety clothing and good extraction
- 9) Optional filler metal to the correct specification. (*In rod form for manual TIG*)

Parameters & Inspection Points

- | | |
|-----------------------------------|--------------------------------|
| 1) Amperage | 2) Arc Voltage |
| 3) AC/DC & Polarity | 4) Speed of travel |
| 5) Tungsten grade & diameter | 6) Duty cycles |
| 7) Tungsten vertex angle | 8) Connections |
| 9) Gas type, purity and flow rate | 10) Insulation/extraction |
| 11) Ceramic size and condition | 12) Condition of all gas hoses |

Typical Welding Imperfections

- | | |
|------------------------|---------------------------|
| 1) Tungsten inclusions | 2) Surface porosity |
| 3) Crater pipes | 4) Weld or root oxidation |

Advantages & Disadvantages

- | Advantages | Disadvantages |
|--|------------------------------------|
| 1) High quality welds | 1) High skill factor required |
| 2) Low inter-run cleaning | 2) Small range of consumable wires |
| 3) All positional process | 3) Protection for site work |
| 4) Can be mechanised (Orbital TIG) | 4) Low Productivity (O/F) |
| 5) Lowest arc process for H ₂ content | 5) High ozone levels |

WIS 5 Section 11 Exercises:

1) Complete the basic equipment requirements for the TIG processes?

1. A Transformer/Rectifier. (Constant amperage type)

2. _____

3. _____

4. _____

5. _____

6. _____

7. _____

8. _____

2) List 11 further parameter inspection points of the TIG welding process?

1. Amperage

2. Arc voltage

3. AC/DC & polarity

4. travel speed

5. Tungsten electrode ϕ and grade

6. shielding gas (type, flow, purity)

7. Tungsten vertex angle

8. duty cycle

9. Insulation/extraction

10. connection

11. Ceramic size & condition

12. Gas hose condition

3) List 3 further typical imperfections that may be found in TIG welds?

1. Tungsten Inclusions

2. crater pipe

3. weld or root oxidation

4. porosity

4) List 2 further advantages and disadvantages of the TIG welding process?

Advantages

1. High Quality Welds

2. low level of H_2

3. All positional

Disadvantages

1. High Skill Factor Required

2. High ozone level

3. Protection for site work

WIS 5 Welding Inspection

Section 12

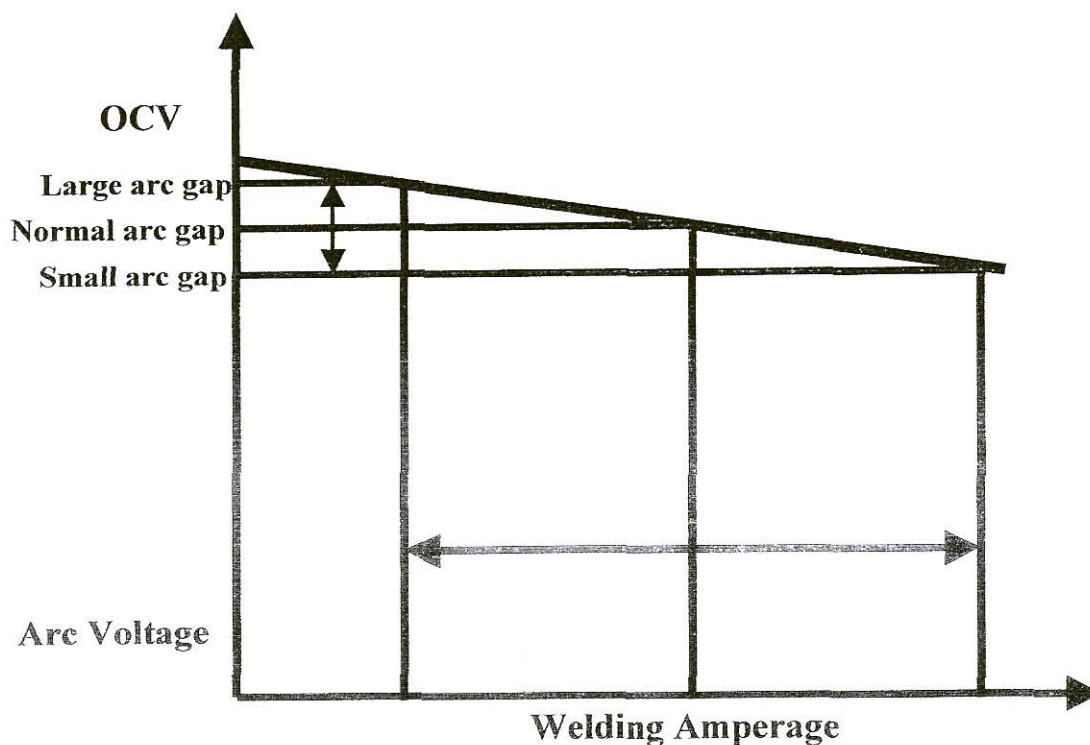
Metal Inert/Active Gas Welding (MIG/MAG GMAW)

Arc Characteristic for MIG & SAW:

In MIG/MAG & SAW welding we require different welding equipment than used for MMA & TIG as the arc length is controlled by voltage.

To achieve this we require a Constant Voltage characteristic power source.

Constant Voltage Volt/Amp Characteristic

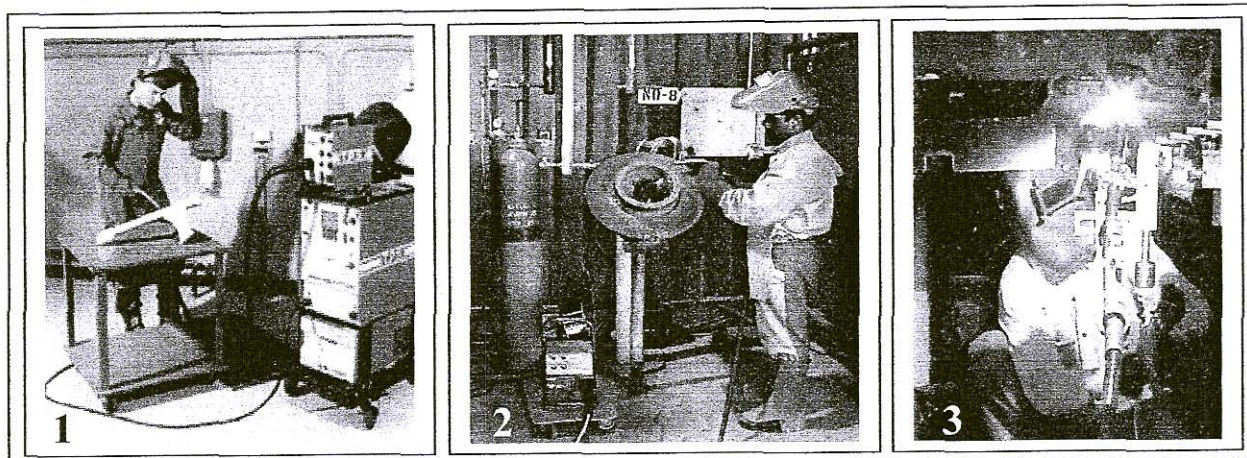


Small change in voltage = Much larger change in amperage.

i.e. 2 volts = 100 amps

When pre-calculating the **welding arc voltage** from the OCV setting it is considered that 1-2 Open Circuit Volts are lost for every 100 amps of welding current being used.

Metal Inert Gas Welding



MIG welding was initially developed in the USA in the late 40's for the welding of aluminium alloys structures using argon or helium gas shielding.

Definitions

MIG Metal Inert Gas (Using an inert shielding gas i.e. argon or helium) 131

MAG Metal Active Gas (i.e. CO₂ Ar/CO₂ or Ar/O₂ mixtures) 135

GMAW Gas Metal Arc Welding (Describes the MIG/MAG process in USA)

FCAW Flux Cored Arc Welding (Describes the flux cored arc process in USA) 114

Introduction

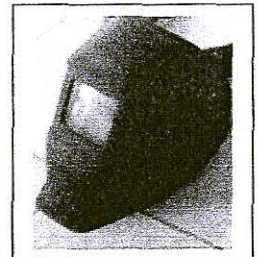
The basic equipment requirements of MIG/MAG welding differ from MMA and TIG as a different type of power source characteristic is required and a continuous wire (from a spool) is supplied at the welding torch head automatically. The shielding gas is supplied externally from a separate cylinder and a separate wire feed unit or internal wire drive mechanism is also required to drive the wire electrode.

The arc is struck by short circuit of the wire on contact with the work piece as it is driven by the drive rolls through the liner then out through the contact tip. The type of metal transfer that occurs is entirely dependant on gas type being used and amperage/WFS (Wire Feed Speed) wire diameter used and the voltage set. As the electric arc length is fully controlled by the power source and the wire is delivered mechanically the process is thus classified as a *semi automatic* process, which may be used manually, mechanised, or fully automated by robotics. Photograph 1 and 2 show the basic process components and photograph 3 shows simple mechanisation in the overhead position.

Metal Inert Gas Welding Basic Equipment Requirements



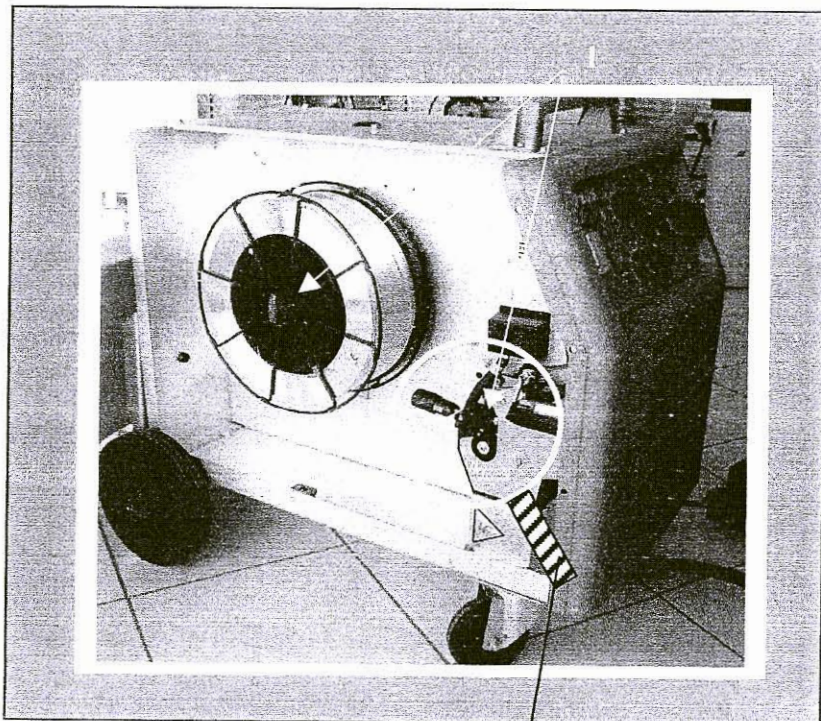
- 1) **Power source. Transformer/Rectifier.** (*Constant Voltage type*)
- 2) **Inverter power source.** (*More compact and portable*)
- 3) **Power hose assembly.** (*Comprising of: Power cable. Water hose. Gas hose*)
- 4) **Liner.** (*Correct type & Ø for wire i.e. Steel for steel and neoprene for aluminium*)
- 5) **Spare contact tips.** (*Correct size for wire diameter*)
- 6) **Torch head assembly.** (*Of a suitable amperage rating*)
- 7) **Power-return cable & clamp.** (*Of a suitable amperage rating*)
- 8) **15kg wire spool.** (*Copper coated & uncoated wires*)
- 9) **Power control panel.** (*OCV. Inductance*)
- 10) **External wire feed unit.** (*Wire feed speed/amperage*)
- 11) **Welding visor.** (*With correct filter glass rating*)



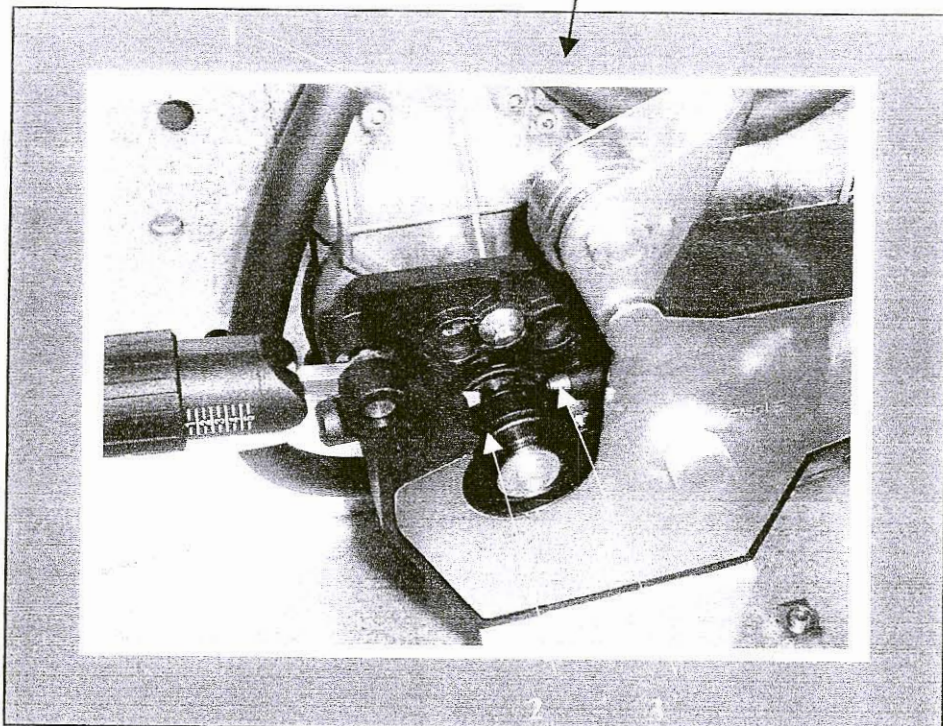
A regulated inert, or active gas supply is also required for this process

The MIG/MAG Wire Drive Assembly

1) An internal wire drive system

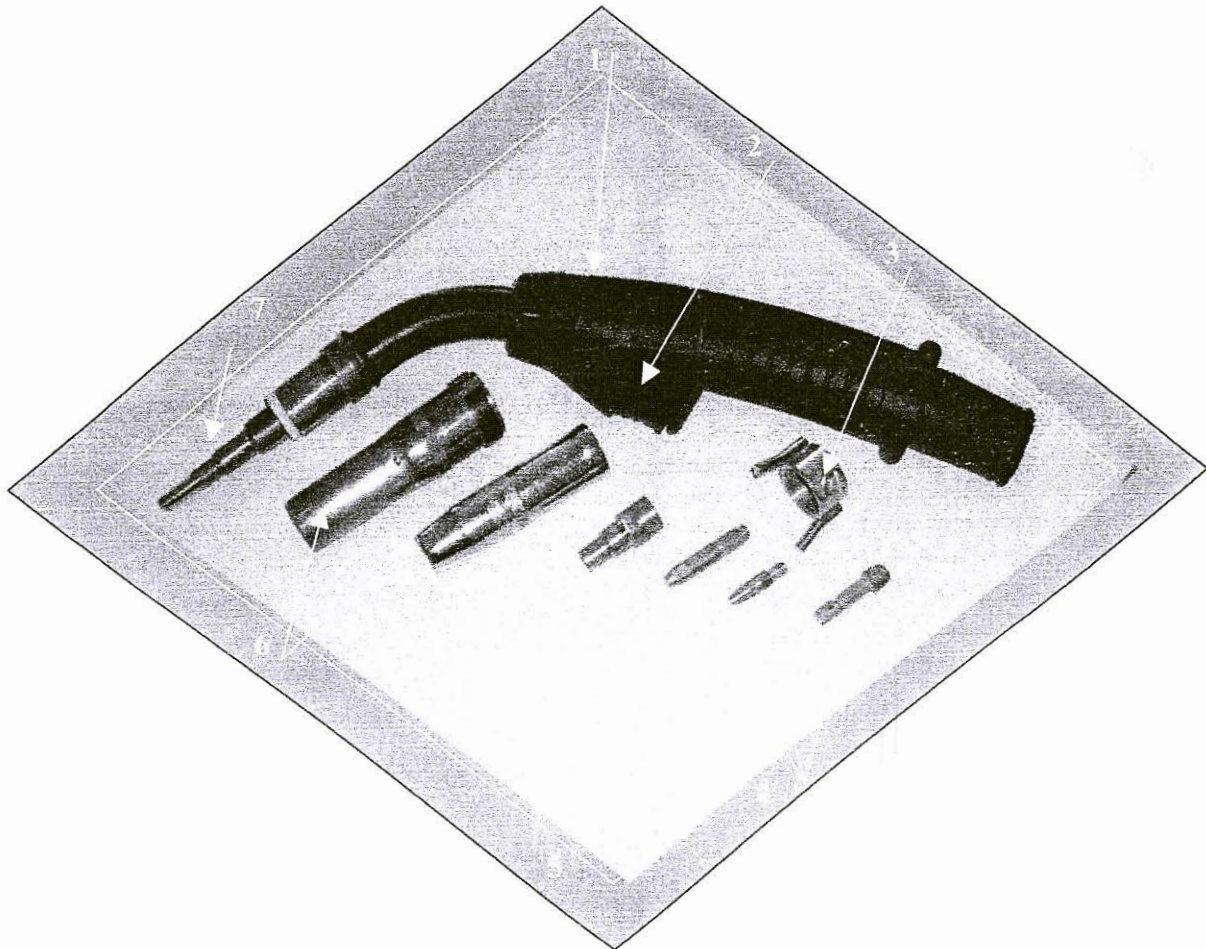


1) Flat plain top drive roller



2) Half groove bottom drive roller 3) Wire guide

The MIG Torch Head Assembly



- 1) Torch body
- 2) On/off or latching switch
- 3) Spot welding spacer attachment
- 4) Contact tips
- 5) Gas diffuser
- 6) Spare shrouds
- 7) Torch head assembly. (*Less the shroud*)

Immediately on pressing the torch on/off (latching) switch, the following occurs:

- a) The gas solenoid opens and delivers the shielding gas
- b) The wire begins to be driven from the reel and through the contact tip
- c) The contactor closes and delivers current to the contact tip
- d) The water pump circulates the cooling water. (If required)

Types of Metal Transfer ~~xxx~~

~~x~~ 1) Dip Transfer

In dip transfer the wire short-circuits the arc between 50 – 200 times/second. This type of transfer is normally achieved with CO₂ or mixtures of CO₂ or O₂ & argon gas + low amps & welding volts (< 24 welding volts). Dip transfer is all positional but with a low deposition rate, penetration and fusion. This is because of the time when the arc is extinguished and only resistance heating takes place. It is mainly used for thin sheet steel < 3mm but may also be used for positional welding of thicker sections. The weld metal is deposited during the short circuit part of the welding cycle.

Low heat input

~~x~~ 2) Spray Transfer

In spray transfer a continuous arc and fine spray of metal transfer is created. This is usually achieved with pure argon or argon CO₂ 5-20% mixtures and higher amps & volts > 26 volts. With steels it is **limited to down-hand butts and H/V fillet** welds but gives higher deposition rate, penetration and fusion than dip transfer because of the continuous arc heating and is mainly used for plate >3mm. When welding aluminium alloys the effect of lower Al density acting against the forces of gravity allows positional welding.

high heat input

~~x~~ 3) Pulsed Transfer

Pulse transfer uses pulses of current to fire a single globule of metal across the arc gap at a frequency between 50 – 300 Pulses/second. Pulse transfer is a development of spray transfer, that gives positional welding capability for steels, combined with controlled heat input, good fusion, and high productivity. It may be used for all sheet steel thickness > 1mm but is mainly used for positional welding of steels > 6mm.

As pulse parameters require *extremely* fine adjustment **Synergic MIG/MAG** equipment is now much more commonly used to control pulse transfer.

4) Synergic Pulsed Transfer

Synergic MIG/MAG was developed in the 1980's and uses microprocessor control to adjust the pulse parameters of the electric arc and maintains optimum conditions for a selection of wire type & diameter, material and gas. The microprocessor control will change all other pulse parameters automatically and immediately, for any change in WFS (Wire feed speed). Equipment may also be used for standard dip, spray and globular transfer. Any change in the equipment type will require **re-approval of the WPQR**.

~~x~~ 5) Globular Transfer

Globular transfer occurs between **dip & spray**, but is not normally used for solid wire MIG-MAG welding but is sometimes used in FCAW. (Flux cored arc welding)

Variable Parameters

1) Wire Feed Speed

Increasing the wire feed speed automatically increases the current in the wire. MIG/MAG wires are generally produced in diameters of 0.6/0.8/1.0/1.2/1.4 & 1.6mm.

2) Voltage

The voltage setting is the most important setting in **spray** transfer as it controls the arc length. In **dip** transfer it also effects the rise of current and the overall heat input into the weld. An increase of both WFS/current and voltage will increase heat input. The welding connections need to be checked for soundness, as any slack connections will give a hot junction where voltage will be lost from the circuit and will affect the characteristic of the welding arc greatly. The voltage setting will affect the type of transfer achievable but this is also **highly dependant on the type of gas being used**.

3) Gases

CO₂ gas cannot sustain pure spray transfer as ionisation potential of the gas is high, because of this and the voltage required to maintain any electric arc in CO₂ gas it does give good penetration, however the arc remains unstable with lots of spatter. Argon has a much lower Ionisation potential and can sustain spray transfer above 24 welding volts. Argon gives a very stable arc and little spatter, but lower penetration than CO₂. We mix both argon and CO₂ gas in mixtures of between 5 – 20% CO₂ in argon to get the benefit of both gases i.e. good penetration with a stable arc and very little spatter. CO₂ gas is much cheaper than argon or its mixtures. 1-2% O₂ or CO₂ in Argon is generally used when welding austenitic or ferritic stainless steels to increase the weld metals fluidity.

4) Inductance

Inductance causes a backpressure of voltage to occur in the wire and operates only when there is a changing current value. In dip transfer welding the current rises as the electrode short circuits on the plate and it is then that the inductance resists the rapid rate of rise of current at the tip of the electrode. This has a **main** effect in **reducing levels of spatter**.

Important Inspection Points/Checks when MIG/MAG Welding

1) The Welding Equipment

A visual check should be made to ensure the welding equipment is in good condition.

2) The Electrode Wire

The diameter, specification and the quality of the wire are the main inspection headings. The level of de-oxidation in the wire is also important with normally Single, Double & Triple de-oxidized wires being available for most C/Mn steels. The **level of deoxidation** is an important factor in minimising occurrence of **porosity in the weld**, while the **quality of copper coating, wire temper & winding** are important in reducing **wire feed problems**.

Quality of wire windings and increasing costs

(a) Random wound. (b) Layer wound. (c) Precision layer wound.

3) The Drive Rolls and Liner

Check the drive rolls are of the correct size for the wire and that the pressure is only hand tight or just sufficient to drive the wire. Any excess pressure will deform the wire to an oval shape. This will make the wire very difficult to drive through the liner and result in arcing in the contact tip and excessive wear of the contact tip and liner. Check that the brake is also correctly tightened to stop over feed of the wire from the inertia of the spool. Check that the liner is the correct type and size for the wire, a size of liner will generally fit 2 sizes of wire i.e. (0.6 & 0.8) (1.0 & 1.2) (1.4 & 1.6) mm diameter. Steel liners are used for steel wires and Teflon or neoprene liners for aluminium wires.

4) The Contact Tip

Check that the contact tip is the correct size for the wire being driven also check the amount of wear frequently. Any loss of contact between the wire and contact tip will reduce the efficiency of current pick. Most steel wires are copper coated to maximise the transfer of current by contact between 2 copper surfaces at the contact tip and it also inhibits corrosion. The contact tip should also be replaced fairly regularly.

5) The Connections

The length of the electric arc in MIG/MAG welding is controlled by the voltage settings. This is achieved by using a constant voltage volt/amp characteristic inside the equipment. Any poor connection in the welding circuit will affect the length, nature and stability of the electric arc, and is thus a major inspection point in this process.

6) Gas & Gas Flow Rate

The type of gas used is extremely important too MIG/MAG welding as is the flow rate from the cylinder, which must be adequate to give good coverage over the solidifying and molten metal, avoiding oxidation and porosity. Excessive gas flow will create turbulence.

7) Other Variable Welding Parameters

Checks should be made for correct WFS voltage, speed of travel, plus all other essential variables of the process given on the approved welding procedure.

8) Safety Checks

Checks should be made on the current carrying capacity or duty cycle of equipment and electrical insulation. Correct extraction systems should be in use to avoid exposure to ozone and fumes.

A check should always be made to ensure that the welder is qualified to weld the procedure being employed.

Typical Welding Imperfections

- 1) **Silica inclusions** (On ferritic steels only) caused by poor inter-run cleaning
- 2) **Lack of sidewall fusion** mainly during *dip transfer* using *excessive inductance*
- 3) **Porosity** caused from loss of gas shield and low tolerance to contaminants
- 4) **Burn through** from using the incorrect metal transfer mode on sheet metals

Advantages of Flux Cored Arc Welding

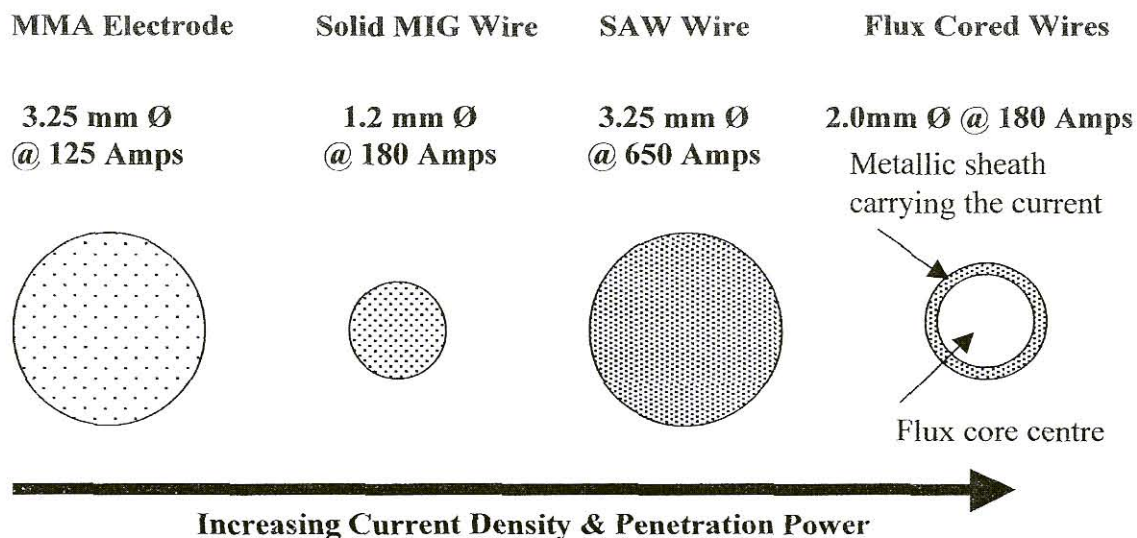
In the mid 80's the development of *Self-shield 114* and *Dual-shield FCAW 146/147* was a major step in the successful application of *on-site* semi automatic welding that has also enabled a much wider range of materials to be welded. The wire consists of a metal sheath containing a granular flux. The flux may contain many elements and compounds normally used in MMA electrodes and also has good positional welding capability thus the process has found popularity in industry on a wide range of fabrication applications.

Gas producing elements and compounds may be added to the flux core thus the process can become independent of any separate gas shielding, which had restricted the use of conventional MIG/MAG welding in field applications. "*Dual Shield*" wires obtain gas shielding from a combination of both compounds in the flux and a separate shielding gas.

Most wires are sealed mechanically and hermetically with various forms of joint. The effectiveness of the joint of the wire is an inspection point of cored wire welding particularly with wires containing basic fluxes as moisture can easily be absorbed into a damaged or poor seam. It is sound practise when using basic cored wires to discard the first meter of a new reel if any doubt remains about its storage history as any moisture can be freely absorbed up through the core of flux *if incorrectly stored*. The baking of cored wires is ineffective and will do nothing to restore the condition of a contaminated flux within a wire.

A further advantage of flux cored wire welding is that it produces very high levels of penetration. This is achieved via the high amount of *current density* in the wire, or in other words the amount of current carried in the available CSA of the conductor. This area is very small in flux-cored wires in comparison with other welding processes as is shown below. The higher the current density then the higher is the penetration factor.

The amperage values given are typical for each process and wire diameter only:



Summary of Solid Wire MIG/MAG GMAW

Equipment requirements

- 1) A Transformer/Rectifier. (*Constant voltage type*)
- 2) A power and power return cable. (*Of a suitable amperage rating*)
- 3) An Inert, active, or mixed shielding gas. (*Argon. CO₂ or mixture*)
- 4) Gas hose, flow meter, and *gas regulator. (**Correct for gas type and flow rates*)
- 5) MIG torch (*Of a suitable amperage rating*) hose package, diffuser, contact tip & shroud
- 6) Wire feed unit with drive rolls and liner. (*Correct drive roll and liner size for wire Ø*)
- 7) Electrode wire to correct specification and diameter. (*1kg or 15kg spool*)
- 8) Correct visor/glass, all safety clothing and good extraction

Parameters & Inspection Points

- | | |
|-----------------------------------|---|
| 1) WFS/Amperage | 2) OCV & Welding voltage |
| 3) Wire type & diameter | 4) Gas type & flow rate |
| 5) Contact tip size and condition | 6) Roller type, size and pressure |
| 7) Liner size | 8) Inductance settings |
| 9) Insulation/extraction | 10) Connections. (<i>Voltage drops</i>) |
| 11) Duty cycles | 12) Travel speed, direction & angles |

Typical Welding Imperfections

- | | |
|----------------------|---|
| 1) Silica inclusions | 2) Lack of fusion. (<i>Mainly dip transfer</i>) |
| 3) Surface Porosity | 4) Burn through. (<i>Using spray for sheet</i>) |

Advantages & Disadvantages

Advantages

- 1) High productivity. (*O/F*)
- 2) Easily automated. (*Robotics*)
- 3) All positional. (*Dip & Pulse*)
- 4) Wide material thickness range
- 5) Continuous electrode

Disadvantages

- 1) Lack of fusion. (*Excessive inductance*)
- 2) Small range of solid wires
- 3) Protection for site working
- 4) Complex equipment
- 5) High ozone levels

WIS 5 Section 12 Exercises:

- 1) Complete the basic equipment requirements for the MIG/MAG processes?

1. A Transformer/Rectifier. (Constant voltage type)

2. _____

3. _____

4. _____

5. _____

6. _____

7. _____

8. _____

- 2) List 11 further parameter inspection points of the MIG/MAG welding process?

1. Amperage/Wire Feed Speed

2. _____

3. _____

4. _____

5. _____

6. _____

7. _____

8. _____

9. _____

10. _____

11. _____

12. _____

- 3) List 3 further typical imperfections that may be found in MIG/MAG welds?

1. Silica Inclusions

2. _____

3. _____

4. _____

- 4) List 2 further advantages and disadvantages of the MIG/MAG welding process?

Advantages

Disadvantages

1. High Productivity (O/F)

1. Lack of Fusion (Excessive Inductance)

2. _____

2. _____

3. _____

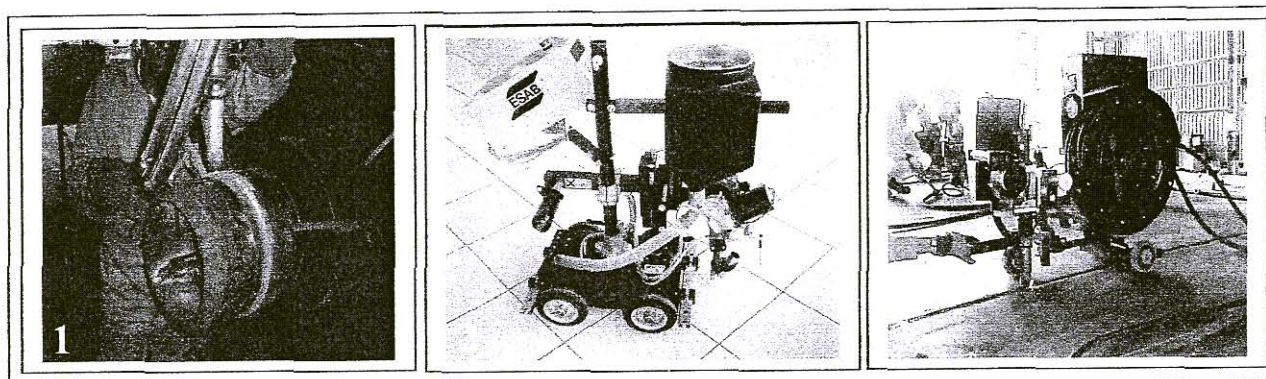
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WIS 5 Welding Inspection

Section 13

Submerged Arc Welding (SAW)

Submerged Arc Welding:



SAW or Submerged arc welding was developed in the Soviet Union during the 2nd world war as an economical means of welding thick steel sections.

Definitions

Submerged Arc Welding (UK) 121
 SAW (USA)

Introduction

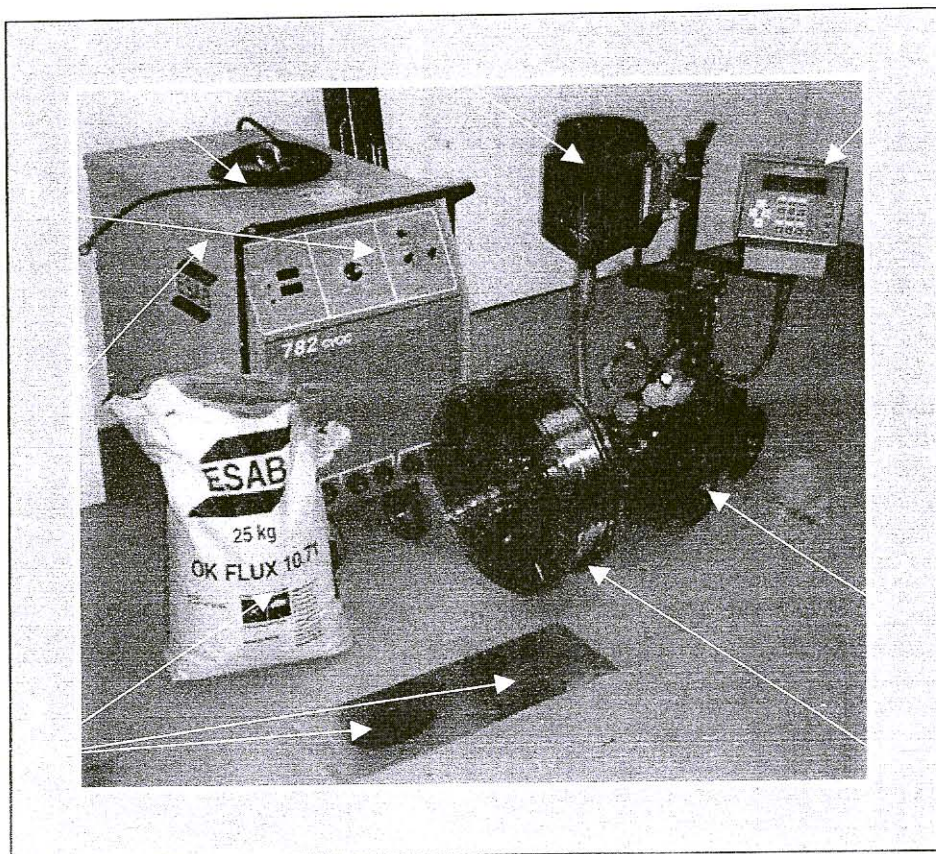
This welding process is normally mechanised and uses both constant voltage/current power sources. As amperages range from 100 to over 2,000 amps this process has a very *high current density* in the wire with *deep penetration* and dilution into base metal.

The arc is struck in the same manner as MIG and is generally aided by the linear movement of the electrode tip across the surface of the run on tab though H/F arc striking is also possible on some equipment. As its name suggests the arc is submerged beneath a covering of flux that is of granular nature.

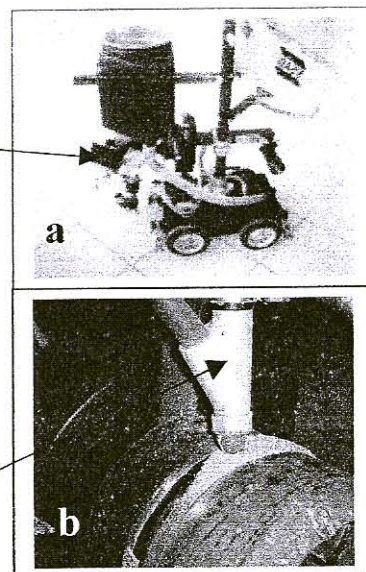
The process is restricted in position and is generally used for thickness of over 10mm. *Run-on and run-off tabs* are normally used on welded seams as this allows the welding arc to settle to its required conditions prior to the commencement of the actual welding seam and the run off plate compensates for this condition at the end of the weld. Both plates are removed after the weld seam has been completed. The arc is normally formed as the point of the wire comes into moving contact with the plate. The flux blanket helps to protect the arc from the atmosphere and decomposes in the heat of the arc to form a gaseous protective shield, adding any alloying elements and de-oxidants that are contained in the flux compounds. The flux also produces a slag that forms a protective barrier to the cooling weld in a similar manner to a MMA flux.

Photograph 1 shows a stationary SAW head with rotated pipe and 2 shows a motorised tractor unit. Photograph 3 shows a mobile (*hand guided*) carriage assembly that is being used for welding deck plates.

Submerged Arc Welding Basic Equipment Requirements



- 1) Welding carriage control panel
- 2) Welding carriage assembly
- 3) Reel of wire
- 4) Granulated flux
- 5) Transformer rectifier
- 6) Power source control panel
- 7) Power return cable. (*Of a suitable amperage rating*)
- 8) Flux hopper (With delivery/recovery system)



A full SAW welding head assembly (**b**) with contact tube & wire/flux delivery mechanisms is an **essential** equipment requirement of the SAW process. This may be carried on a motorised tractor unit. (As shown in **a**) Alternatively booms and manipulators may be used.

Immediately on pressing the switch, the following occurs:

- a) The flux is released forming a layer beneath the torch head
- b) The wire begins to feed and strikes the arc
- c) The contactor closes and delivers current to the contact tip
- d) The tractor begins to move (If mechanised)

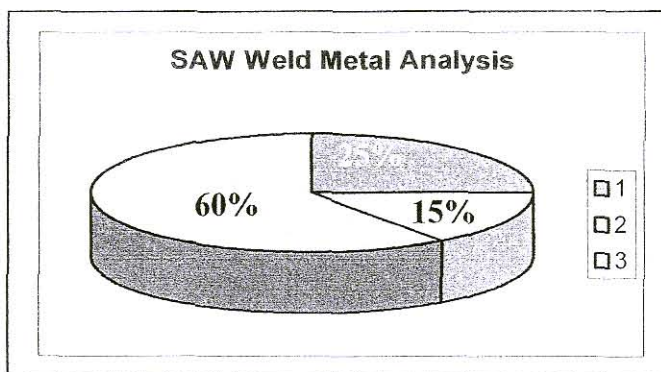
Because of the nature of the granular flux the use of Submerged Arc Welding for positional welding has been restricted to the flat position. However, the process has been continually developed and is now capable of certain degree of positional welding with an addition of some simple extra equipment. (i.e. flux dams) Limitations exist other than the positional capability of the SAW process such as material thickness generally $> 10 \text{ mm t}$ and when full penetration welds from one side are required without the use of a backing bar or backing strips. (The use of a backing bar is shown on page 13.5)

One common application of SAW is in the welding of "*spirally welded pipe*" where a fixed unit is stationed inside the pipe for the internal seam with an additional fixed unit placed on the top of the pipe for the outer seam resulting in a full penetration weld.

Other factors that should be taken into consideration are the toughness requirements of the joint as the arc energy input is comparatively high. *Arc blow* can also be a major problem as magnetic field strength is proportional to the current and with currents in SAW commonly $> 1,500 \text{ amps}$ *arc blow* is not uncommon. It can be minimised by the use of tandem wire systems. (Leading wire on DC+ and the trailing wire on AC producing opposing magnetic fields) The use of double or multi run techniques also has effects on properties of both weld metal and HAZ.

The resultant SAW weld metal composition is often difficult to predict as the weld is made up from 3 elements. A *typical* set of values is given below but this can change critically with small changes in the welding parameters.

- 1) The Electrode. (25%)
- 2) Elements in the flux. (15%)
- ? 3) Dilution. (60%)



The proportion of these elements in the final weld deposit will vary depending on the welding parameters set and a variation in *arc voltage* will change the *arc length* and thus affect the amount of flux being melted and overall % of alloying elements in the final weld.

Variable Parameters

1) Wire Feed Speed

Increasing the wire feed speed automatically increases the current in the wire. The density of the current in the wire is dependant on the cross section area of the wire. The higher the density of the current then the higher is the level of penetration and fusion that is obtained.

2) Voltage

The Open Circuit and welding arc voltages are critical variables in any SAW WPS affecting bead shape and penetration profile. The arc voltage also governs arc length beneath the flux layer and any *changes in arc length* will radically *alter weld metal composition* mainly due to changes in elements from the flux being alloyed into the weld. Any changes in weld metal composition may in turn alter the mechanical properties, thus great care should always be taken in *ensuring tight connections of all welding cables*.

3) Electrode stick out

This variable parameter is the value of distance of the welding head assembly from the work surface. It has an affect on welding amperage, as power will be consumed in the resistance heating of the wire from the tip of the contact tip to the end of the wire. The electrode stick out value should be given (in metric mm or imperial inches) on the WPS.

4) Flux depth

The flux depth is controlled by the flux feed rate and the distance from the feeding head to the work surface. The flux depth needs to be sufficiently high to cover the arc, though too high a flux depth may also cause problems in the weld.

5) Travel Speed

As SAW is most often a mechanised process the travel speed can be considered as an important variable parameter affecting penetration and bead profile. The correct travel speed for the joint should be given on the approved welding procedure specification sheet.

Important Inspection Points/Checks when Submerged Arc Welding

1) The Welding Equipment

A visual check should be made to ensure the welding equipment is in good condition.

2) The Welding Head Assembly & Flux Delivery System

Checks should be made that the diameter, specification of the electrode wire and the specification and mesh size of flux being used is correct to the approved WPS.

Checks should be made that the drive system has correct roller diameter and contact tip fitted and that the flux delivery system is operational. A check also should be made that the electrode stick out dimension is correct, and if using run on and run off plates that these are fitted and tacked in place correctly.

3) Current & Polarity

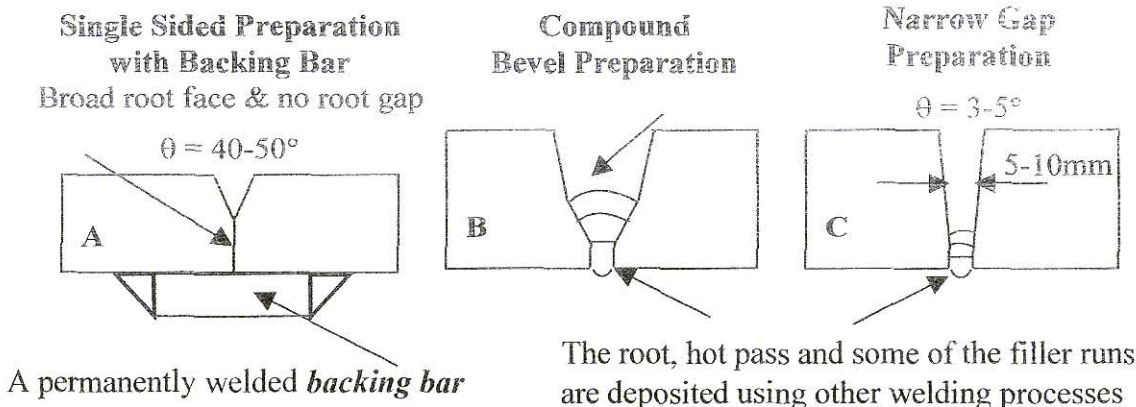
Checks should be made to ensure that the type of current being used is correct and if DC that the polarity is correct and that the current range is within that given on the procedure. Multi wire welding may use both types of current i.e. DC + leading wire with an AC trailing wire as this improves welding times and offsets the effects of "arc blow". If using multi wire process the angle of the trailing wire must also be checked. All parameters should be given on the approved WPS.

4) Other Variable Welding Parameters

Other procedural parameters may include the use of *backing bar or backing strips* particularly when welding from a **single side**. In addition to the inspection points mentioned previously checks should also be made to ensure that all welding parameters should be within those given on the WPS.

- (A) A typical **single sided** weld preparation for SAW with use of a backing bar to control the effects of high levels of weld penetration with the process.
- (B) A single sided full penetration weld without the use of a backing or strip, the root run, hot pass and a number of filling runs would be put in using TIG MMA or MIG to allow for a sufficient base prior to using the Submerged Arc Welding process.
- (C) SAW may also be used in a **Narrow Gap** type preparation where the included angles range between $3-5^\circ$ and the gap width between 5 - 10 mm.

Narrow gap welding preparations may also be used with the TIG and MIG welding processes, using *specialised welding heads and wire delivery systems*.



5) Safety Checks

Checks should be made on the current carrying capacity, or duty cycle of equipment, and that all electrical insulation is sound. Correct extraction systems should be in use to avoid exposure to toxic fumes.

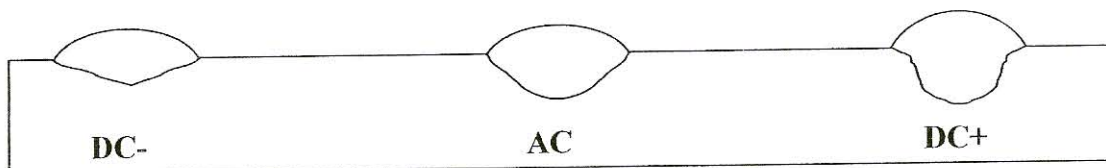
Typical Welding Imperfections

- 1) **Porosity** mainly from using damp welding fluxes or improperly cleaned plates
- 2) **Centreline cracks** mainly caused by high dilution and sulphur pick up
- 3) **Shrinkage cavities** mainly caused by the high depth/width ratio weld profile
- 4) **Lack of fusion** mainly caused by arc blow or poor tracking on double sided welds

Effects on weld profile when changing SAW parameters:

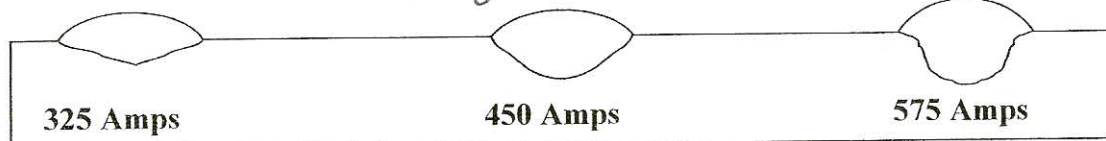
The weld surface/penetration profiles below represent the typical effects of changing SAW welding process variable parameter on a specific SAW Single Wire & Flux Combination. Optimum parameters for the wire flux combination used are given in the central column.

AC/DC & Polarity:



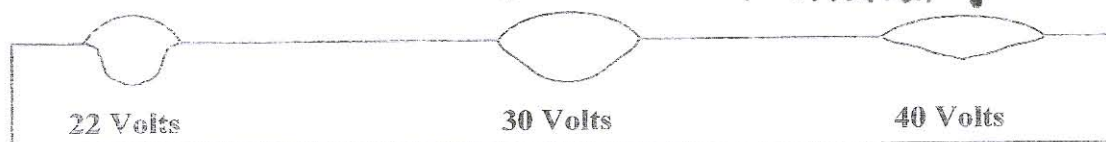
Amperage:

Amperage $\uparrow \Rightarrow$ Penetration $\uparrow$



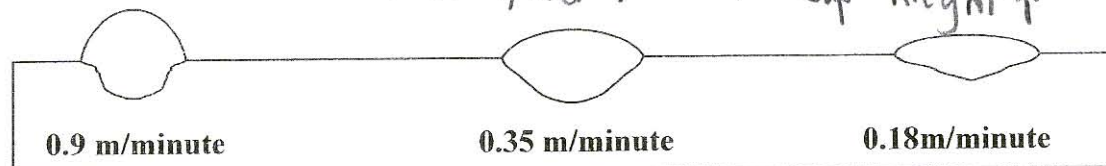
Arc Voltage:

voltage $\uparrow \Rightarrow$ weld width $\uparrow$
Penetration $\downarrow$



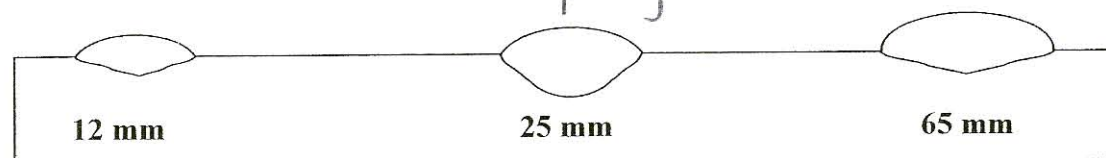
Travel Speed:

Travel speed $\uparrow \Rightarrow$ weld width $\downarrow$
cap height $\uparrow$



Electrode Stick-out:

$\uparrow \Rightarrow$ weld width $\uparrow$
cap height $\uparrow$



Any further changes in welding technique &/or wire $\varnothing$ &/or + wire flux combination will also greatly effect the levels of penetration achievable &/or surface weld profile shown.

Summary of Sub Arc Welding: xxx

Equipment requirements

- 1) A Transformer/Rectifier. (*Constant voltage/current type***)
- 2) A power and power return cable. (*Of a suitable amperage rating*)
- 3) A torch head assembly. (*Of a suitable amperage rating*)
- 4) A granulated flux of the correct type/specification and mesh size
- 5) A flux delivery system
- 6) A flux recovery system
- 7) Electrode wire to correct specification and diameter
- 8) Correct safety clothing

Parameters & Inspection Points:

- | | |
|----------------------------------|---------------------------------|
| 1) AC/DC WFS/Amperage | 2) OCV & Welding Voltage |
| 3) Flux type and mesh size | 4) Flux condition. (Baking etc) |
| 5) Electrode wire and condition | 6) Wire specification |
| 7) Flux delivery/recovery system | 8) Electrode stick-out |
| 9) Insulation/duty cycles | 10) Connections |
| 11) Contact tip size/condition | 12) Speed of travel |

Typical Welding Imperfections

- | | |
|---|---|
| 1) Shrinkage cavities (<i>High d:w</i>) | 2) Solidification cracks (<i>High % dilution</i>) |
| 3) Lack of fusion (<i>Arc Blow</i>) | 4) Porosity |

Advantages & Disadvantages

Advantages

- 1) Low weld-metal costs
- 2) Easily mechanised
- 3) Low levels of ozone production
- 4) High productivity. (O/F)
- 5) No visible arc light

Disadvantages

- 1) Restricted in positional welding
- 2) High probability of arc-blow. (DC+/-)
- 3) Prone to shrinkage cavities
- 4) Difficult penetration control
- 5) Relatively high equipment costs

** Constant voltage power sources are mainly used for all wire diameters, though constant amperage power sources may be optionally used for larger diameter wires. Constant voltage power sources are far more commonly used in Submerged Arc Welding.

WIS 5 Section 13 Exercises:

- 1) Complete the basic equipment requirements for the SAW processes?

1. A Transformer/Rectifier. (Type may vary with wire Ø**)

2. Power & Power return cable (Suitable for amperage rating)

3. Flux delivery system

4. Torch head assembly

Granulated 5. flux (correct type / specification / mesh size)

6. Electrode wire (correct specification & Ø)

7. correct safety clothing

8. Flux recovery system

- 2) List 11 further parameter inspection points of the SAW welding process?

1. Amperage/WFS? (**Type)

2. OCV / Arc Voltage

3. Electrode wire size / spec

4. Electrode Condition

5. flux type / mesh size

6. flux condition (baking, etc)

7. connection

8. Insulation / duty cycle

9. contact tip (size, condition)

10. Electrode stick out

11. travel speed

12. Flux delivery / recovery system

- 3) List 3 further typical imperfections that may be found in SAW welds?

1. Shrinkage Cavities

2. Solidification Crack (High % dilution)

3. Lack of fusion (Arc blow)

4. Porosity

- 4) List 2 further advantages and disadvantages of the SAW welding process?

Advantages

1. Low Weld Metal Costs

2. _____

3. _____

Disadvantages

1. Restricted in Position

2. Arc blow

3. Difficult penetration control

WIS 5 Welding Inspection

Section 14

Welding Consumables for MMA TIG MIG/MAG & SAW

Welding Consumables:

Welding consumables are defined as all that is used up during the production of a weld.

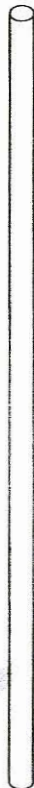
This list could include all things used up in the production of a weld, however we normally refer to welding consumables as those items used up by a particular welding process.

These are namely

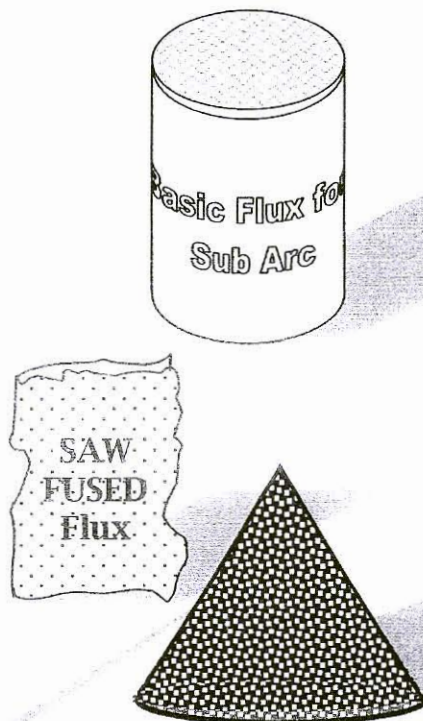
Electrodes



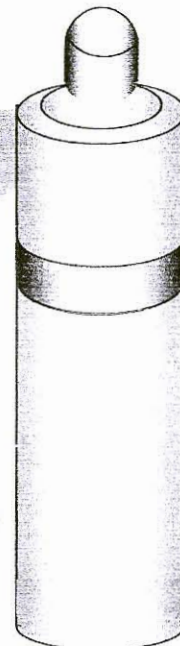
Wires



Fluxes



Gases



When inspecting welding consumables arriving at site it is important that they are inspected for the following:

- 1) **Size**
- 2) **Type or Specification**
- 3) **Condition**
- 4) **Storage**

The checking of *suitable storage conditions* for all consumables is a *critical* part of the welding inspectors duties.

Consumables for MMA Welding

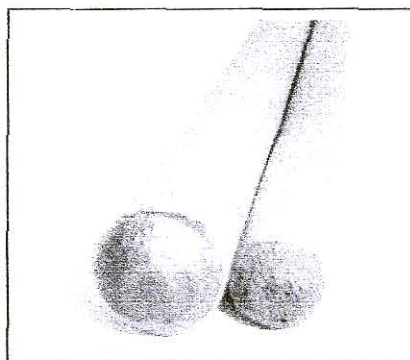
Welding consumable for MMA consist of a core wire typically between 350 and 450mm length and from 2.5 - 6mm diameter. Other lengths and diameters are also available. The wire is covered with an extruded flux coating. The core wire is generally of low quality steel (Rimming Steel) as the weld can be considered as a casting and therefore the weld can be refined by the addition of cleaning or refining agents in the flux coating. The flux coating contains many elements and compounds that all have a variety of jobs during welding. Silicon is mainly added as a de-oxidising agent (in the form of Ferro silicate), which removes oxygen from the weld metal by forming the oxide Silica. Manganese additions of up to 1.6% will improve the strength and toughness of steel. Other metallic and non-metallic compounds are added that have many functions, **some** of which are as follows:

- 1) **To aid arc ignition**
- 2) **To improve arc stabilisation**
- 3) **To produce a shielding gas to protect the arc column**
- 4) **To refine and clean the solidifying weld-metal**
- 5) **To form a slag which protects the solidifying weld-metal**
- 6) **To add alloying elements**
- 7) **To control hydrogen content of the weld metal**
- 8) **To form a cone at the end of the electrode, which directs the arc**

Electrodes for MMA/SMAW are grouped depending on the main constituent in their flux coating, which in turn has a major effect on the weld properties and ease of use. The common groups are given below:

Group	Constituent	Shield gas	Uses	AWS A 5.1
Rutile	Titania	Mainly CO ₂	General purpose	E 6013
Basic	Calcium compounds	Mainly CO ₂	High quality	E 7018
Cellulosic	Cellulose	Hydrogen + CO ₂	Pipe root runs	E 6010

Some basic electrodes may be tipped with a carbon compound, which eases arc ignition.



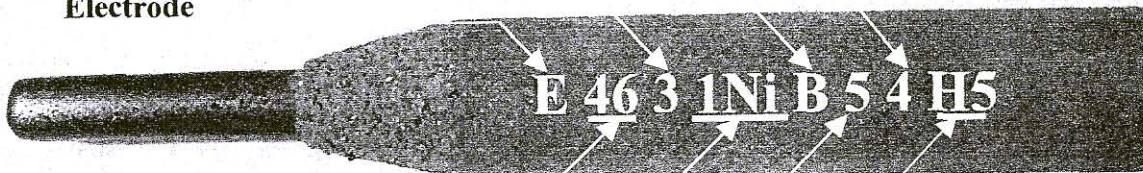
A Typical Electrode Specification to BS EN 499

Positional capabilities

Flux coating type

Toughness 47 Joules

Electrode



Tensile & Yield Strength

Any light alloying composition

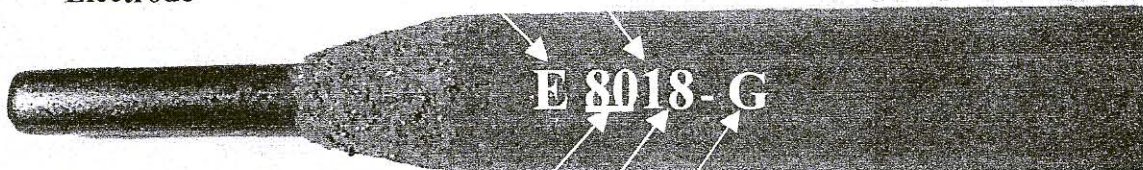
Electrical parameters and efficiency

Low Hydrogen Potential (After Baking)

A Typical Electrode Specification to AWS A5.1 & A5.5

Positional Capabilities

Electrode



Tensile Strength x 1000 PSI

Electrode Coating &

Electrical Characteristics

AWS A5.5 for Low Alloy Steels

A Typical BS EN 499 Specification E 46 3 1Ni B 5 4 H5
Reference given in box letter: A) B) C) D) E) F) G)

A) Tensile strength			
Symbol	Min Yield Strength N/mm ²	Tensile Strength N/mm ²	Min E %
35	355	440-570	22
38	380	470-600	20
42	420	500-640	20
46	460	530-680	20
50	500	560-720	18

C) Alloying (Deposited weld chemical composition)			
Symbol	Mn	Mo	Ni
None	2.0	-	-
Mo	1.4	0.3-0.6	-
MnMo	>1.4-2.0	0.3-0.6	-
1Ni	1.4	-	0.6-1.2
2Ni	1.4	-	1.8-2.6
3Ni	1.4	-	>2.6-3.8
Mn 1Ni	>1.4-2.0	-	0.6-1.2
1NiMo	1.4	0.3-0.6	0.6-1.2
Z	Any other agreed		

E) Electrical characteristic + recovery %		
Symbol	Recovery %	Current type
1	< 105	ac + dc
2	< 105	dc
3	> 105 < 125	ac + dc
4	> 105 < 125	dc
5	> 125 < 160	ac + dc
6	> 125 < 160	dc
7	> 160	ac + dc
8	> 160	dc

G) Hydrogen Content of deposited weld metal	
Symbol	Max H ₂ Content ml/100mgm
H 5	5
H 10	10
H 15	15

B) Toughness at minimum impact energy 47 Joules	
Z	No requirement
A	+20
0	0
2	-20
3	-30
4	-40
5	-50
6	-60

D) Covering types	
A	Acid
C	Cellulosic
R	Rutile
RR	Rutile thick covering
RC	Rutile/Cellulosic
RA	Rutile/Acid
RB	Rutile/Basic
B	Basic

F) Welding position	
Symbol	Position
1	All positions
2	All positions except Vertical Down
3	Flat Butt & Fillets + HV Fillets.
4	Flat Butt & Fillets
5	Vertical Down + positions of symbol 3

The **strength, toughness, coating** plus any light **alloying elements** of BS EN 499 (if applicable) are the **mandatory** elements of information that **shall** be shown on all electrodes. All other information is normally given on the electrode carton.

A Typical AWS A5.1 & A5.5 Specification E 80 1 8 G

Reference given in box letter:

A) B) C) (D For A5.5 only)

A) Tensile + Yield Strength and E%			
Code	Min Yield PSI x 1000	Min Tensile PSI x 1000	Min E % In 2" min
General			
E 60xx	48,000	60,000	17-22
E 70xx	57,000	70,000	17-22
E 80xx	68-80,000	80,000	19-22
E 100xx	87,000	100,000	13-16
Specific Electrode Information for E 60xx and 70xx			
E 6010	48,000	60,000	22
E 6011	48,000	60,000	22
E 6012	48,000	60,000	17
E 6013	48,000	60,000	17
E 6020	48,000	60,000	22
E 6022	Not required	60,000	Not required
E 6027	48,000	60,000	22
E 7014	58,000	70,000	17
E 7015	58,000	70,000	22
E 7016	58,000	70,000	22
E 7018	58,000	70,000	22
E 7024	58,000	70,000	17
E 7028	58,000	70,000	20

B) Welding Position	
1	All Positional
2	Flat butt & H/V Fillet Welds
3	Flat only

Note: Not all Category 1 electrodes can weld in the *Vertical Down* position.

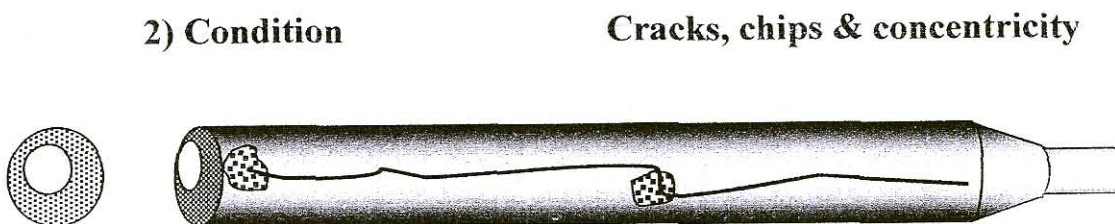
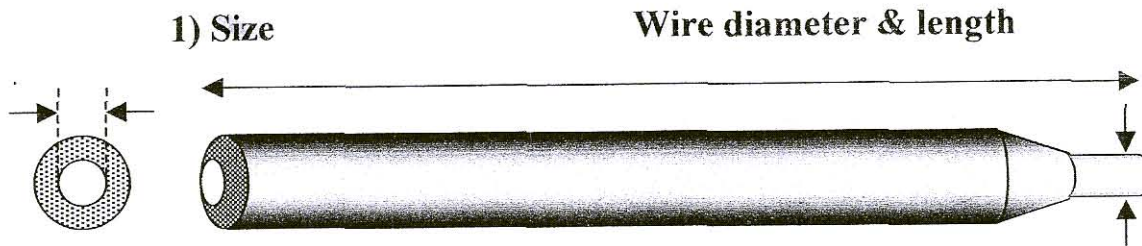
V Notch Impact Izod test (ft.lbs)	Radiographic Standard
20 ft.lbs at -20° F	Grade 2
20 ft.lbs at -20° F	Grade 2
Not required	Not required
Not required	Grade 2
Not required	Grade 1
Not required	Not required
20 ft.lbs at -20° F	Grade 2
Not required	Grade 2
20 ft.lbs at -20° F	Grade 1
20 ft.lbs at -20° F	Grade 1
20 ft.lbs at -20° F	Grade 1
Not required	Grade 2
20 ft.lbs at 0° F	Grade 2

C) Electrode Coating & Electrical Characteristic		
Code	Coating	Current type
E xx10	Cellulosic/Organic	DC + only
E xx11	Cellulosic/Organic	AC or DC +
E xx12	Rutile	AC or DC -
E xx13	Rutile + 30% Fe Powder	AC or DC +/-
E xx14	Rutile	AC or DC +/-
E xx15	Basic	DC + only
E xx16	Basic	AC or DC +
E xx18	Basic + 25% Fe Powder	AC or DC +
E xx20	High Fe Oxide content	AC or DC +/-
E xx24	Rutile + 50% Fe Powder	AC or DC +/-
E xx27	Mineral + 50% Fe Powder	AC or DC +/-
E xx28	Basic + 50% Fe Powder	AC or DC +

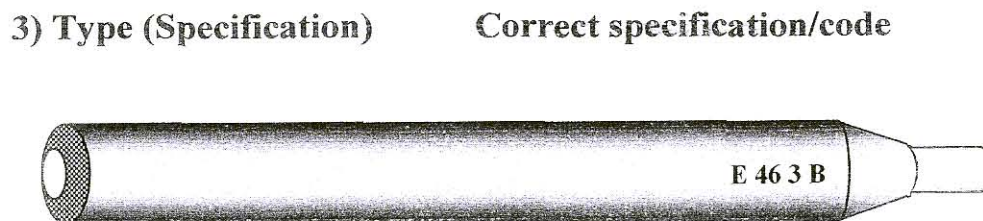
D) AWS A5.5 Low Alloy Steels	
Symbol	Approximate Alloy Deposit
A1	0.5% Mo
B1	0.5% Cr + 0.5% Mo
B2	1.25% Cr + 0.5% Mo
B3	2.25% Cr + 1.0% Mo
B4	2.0% Cr + 0.5% Mo
B5	0.5% Cr + 1.0% Mo
C1	2.5% Ni
C2	3.25% Ni
C3	1%Ni + 0.35%Mo + 0.15%Cr
D1/2	0.25 – 0.45%Mo + 0.15%Cr
G	0.5%Ni or/& 0.3%Cr or/& 0.2%Mo or/& 0.1%V
For G only 1 element is required	

The above tables giving data for BS EN 499. AWS A5.1 and A5.5 are not fully complete and are also subject to periodic changes. Thus latest revisions of the relevant standard should always be consulted for full and up to date electrode classification and technical data.

Inspection Points for MMA Consumables:



*All electrodes showing signs of the effects of **corrosion** should be **discarded**.*



Checks should also be made to ensure that **basic electrodes** have been through the correct **pre-use procedure**. Having been baked to the correct temperature (typically 300-350°C) for **1 hour** and then held in a holding oven (**150 °C max**) before being issued to the welders in **heated quivers**. Most electrode flux coatings will deteriorate rapidly when damp and care should be taken to inspect storage facilities to ensure that they are adequately dry and that all electrodes are stored in conditions of controlled humidity.

Vacuum packed electrodes may be used directly from the carton, only if the vacuum has been maintained. Directions for hydrogen control are always given on the carton and should be strictly adhered to. The cost of each electrode is insignificant compared with the cost of any repair thus basic electrodes that are left in the heated quiver after the day's shift may potentially be re baked but would normally be discarded to avoid the risk of H₂ induced problems.

Consumables for TIG Welding

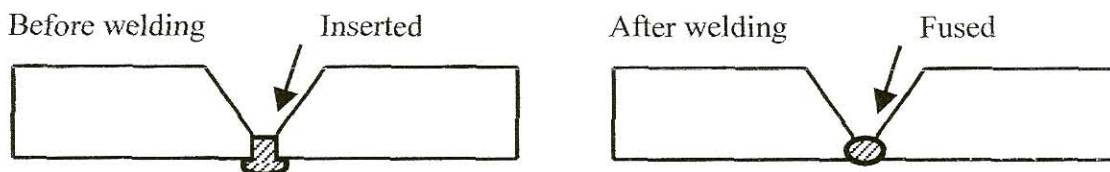
Consumables for TIG/GTAW consist of a wire and gas though tungsten electrodes may also be grouped in this. Though it is considered as a **non-consumable** electrode process the electrode is consumed by erosion in the arc and by grinding and incorrect welding technique. The wire needs to be of a very high quality as normally no extra cleaning elements can be added into the weld. The wire is refined at the original casting stage to a very high quality where it is then rolled and finally drawn down to the correct size.

It is then copper coated and cut into 1m lengths when a code is then stamped on the wire with a manufacturer's or nationally recognised number for the correct identification of chemical composition. A grade of wire is selected from a table of compositions and wires are mostly copper coated which inhibits the effects of corrosion. Gases for TIG/GTAW are generally inert and pure argon or helium gases are generally used for TIG welding. The gases are extracted from the air by liquefaction where argon being more common in air is thus generally cheaper than helium.

In the USA helium occurs naturally thus it is the gas is more often used in the USA. Helium gas produces a deeper penetrating arc than argon, but is less dense (lighter) than air and needs 2 to 3 times the flow rate of argon gas to produce sufficient cover to the weld area when welding down-hand. Argon on the other hand is denser (heavier) than air and thus less gas needs to be used in the down-hand position. Mixtures of argon and helium are often used to balance the properties of the arc and the shielding cover ability of the gas. Gases for TIG/GTAW need to be of the highest purity (99.99% pure). Careful attention and **inspection** should be given to the purging of and the condition of gas hoses, as it is very possible that contamination of the shielding gas can be made through a worn or withered hose.

Tungsten electrodes for TIG welding are generally produced by powder forging technology. The electrodes contain other oxides to increase their conductivity and electron emission and also effect on the characteristics of the arc. Sizes of tungsten electrodes are available off the shelf between 1.6 – 10mm diameter. Ceramic shields may also be considered as a consumable item as they are easily broken, the size and shape of ceramic depending mainly on the type of joint design and the diameter of the tungsten.

A particular consumable item that may be used during the **TIG welding of pipes** is a **fusible insert** often referred to as an **EB Insert** after the **Electric Boat Co' of USA** who first developed it. The insert is normally made of matching material to the pipe base metal composition and is fused into the root during welding as shown below.



Consumables for MIG/MAG Welding

Consumables for MIG/MAG welding consist of a wire and gas. The wire specifications used for TIG welding are also used for MIG/MAG welding as a similar level of quality is required in the wire.

The main purpose of the copper coating of steel MIG/MAG welding wire is to maximise current pick-up at the contact tip and reduce the level of coefficient of friction in the liner with protection against the effects of corrosion being a secondary function.

Wires are available that have not been copper coated as the effects of copper flaking in the liner can cause many wire feed problems. These wires may be coated in a graphite compound, which again increases current pick up and reduces friction in the liner. Some wires including many cored wires are nickel coated.

Wires are available in sizes from 0.6 – 1.6 mm diameter with finer wires available on a 1kg reel though most wires are supplied on a 15kg drum.

Common gases and mixtures used for MIG/MAG welding include:

Gas Type	Process	Used for	Characteristic
Pure Argon	MIG	Spray or Pulse Welding of Steels and Aluminium alloys	Very stable arc with <u>poor penetration</u> and low spatter levels.
Pure CO ₂	MAG	Dip Transfer Welding of Steels	<u>Good penetration</u> Unstable arc and high levels of spatter.
Argon + 5 – 20% CO ₂	MAG	Dip Spray or Pulse Welding of Steels	<u>Good penetration</u> with a stable arc and low levels of spatter.
Argon + 1-2% O ₂ or CO ₂	MAG	Spray or Pulse Welding of Austenitic or Ferritic Stainless Steels <u>Only</u>	Active additive gives good fluidity to the molten stainless, and improves toe blend.

Consumables for Sub Arc Welding

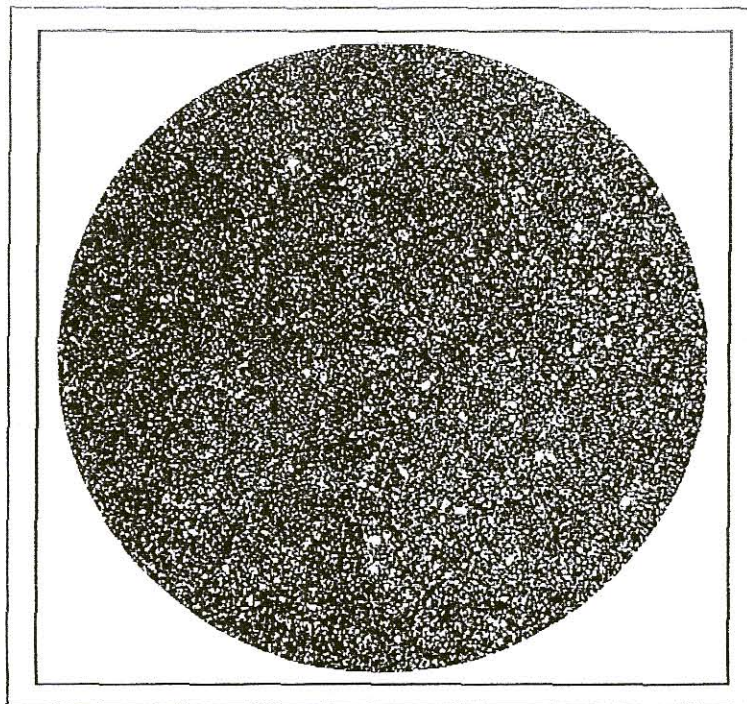
Consumable for Submerged Arc SAW consist of an electrode wire and flux. Electrode wires are normally of high quality and for welding C/Mn steels are generally graded on their increasing Carbon and Manganese content level of de-oxidation.

Electrode wires for welding other alloy steels are generally graded by chemical composition in a table in a similar way to MIG and TIG electrode wires. Fluxes for Submerged Arc Welding are graded by their manufacture and composition. There are 2 normal methods of manufacture known as **fused** and **agglomerated**.

1) Fused fluxes

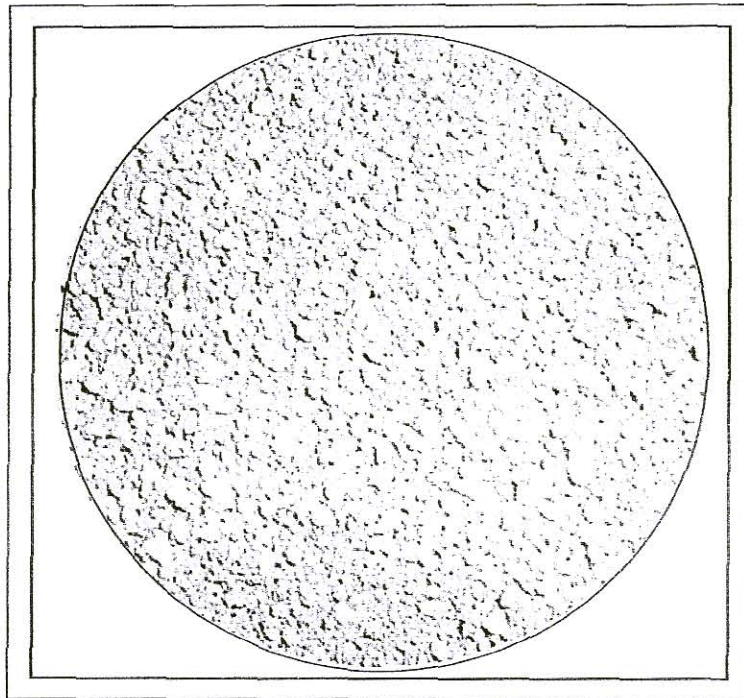
Fused fluxes are mixed together and baked at a very high temperature $> 1,000^{\circ}\text{C}$, where all the components become fused together. When cooled the resultant mass resembles a sheet of coloured glass, which is then pulverised into small particles.

These particles are hard, reflective, irregularly shaped, and cannot be crushed in the hand. It is impossible to incorporate certain alloying compounds into the flux such as Ferro manganese as these would be destroyed in the high temperatures of the manufacturing process. Fused fluxes tend to be of the **acidic type** and are fairly tolerant of poor surface conditions, but produce comparatively low quality weld metal in terms of the mechanical properties of tensile strength and toughness. They are easy to use and produce a good weld contour with an easily detachable slag.



2) Agglomerated fluxes

Agglomerated fluxes on the other hand are a mixture of compounds that are baked at a much lower temperature and are essentially bonded together by bonding agents into small particles. The recognition points of these types of fluxes is easier, as they are dull, generally round granules that are friable (easily crushed) and can also be coloured. Many agents and compounds may be added during manufacture unlike the fused fluxes. Agglomerated fluxes tend to be of the **basic type** and will produce weld metal that is of an improved quality in terms of strength and toughness, at the expense of usability as these fluxes are much less tolerant of poor surface conditions and generally produce a slag that is much more difficult to detach and remove.



It can be seen that the weld metal properties will result from using a particular wire, with a particular flux, in a particular weld sequence and therefore the grading of SAW consumables is given as a function of a **wire/flux combination and welding sequence**.

A typical grade will give values for:

- | | |
|------------------------|----------------------------------|
| 1) Tensile Strength | 2) Elongation % |
| 3) Toughness. (Joules) | 4) Toughness testing temperature |

All consumables for SAW (wires and fluxes) should be stored in a dry and humid free atmosphere. The flux manufacturers handling/storage instructions/conditions should be very strictly followed to minimise any moisture pick up. Any **re-use of fluxes** is totally dependant on applicable clauses within the application standard.

On no account should different types of fluxes be mixed together.

WIS 5 Section 14 Exercises:

- 1) List 4 main inspection points of welding consumables and comment on each point in relation to MMA electrodes?

1. Size: Wire diameter & length of electrodes

2. _____

3. _____

4. _____

- 2) Complete the table of general information below?

Group	Constituent	Shield gas	Uses	AWS A 5.1
Rutile	TiO ₂ (titania)	mainly CO ₂	General purpose	E 6013
Basic	Calcium compounds	mainly CO ₂	High quality	E 7018
Cellulose	cellulose	Hydrogen + CO ₂	Root run of pipes	E 6010

- 3) Indicate the main information given on the electrode below to BS EN 499?



E Electrode

B Type of flux coating

50 Tensile & yield strength

3 Electrical characteristic & efficiency

4 Toughness

1 Position

3 Ni Light alloy composition

H 10 H₂ content (after baking)

- 4) Identify a positive recognition point of a fused/agglomerated SAW flux?

Fused:

condition

Agglomerated:

1. Tolerant to poor surface

1. Good toughness & tensile strength

- 5) Complete the table of information below for MIG/MAG welding Gases?

Gas Type	Process	Used for	Characteristic
Argon + 5 - 20% CO ₂	MAG	Dip Spray or Pulse Welding of Steels	Good penetration, stable arc low level of spatter
Argon + 1-2% CO ₂	MAG	Spray, pulse Au, Fe stainless steel	Gives fluidity to molten stainless improving the weld toe blend

WIS 5 Welding Inspection

Section 15

Non-Destructive Testing

Non-Destructive Testing:

NDT or Non Destructive Testing may be used as a means to *evaluate* the quality of a component by assessing its internal and/or external integrity, but without destroying it.

There are many methods of NDT some of which require a very high level of skill both in application and analysis and therefore NDT operators for these methods require a high degree of training and experience to apply them successfully.

The four principle methods of NDT used are:

- 1) *Penetrant testing*
- 2) *Magnetic particle testing*
- 3) *Ultrasonic testing*
- 4) *Radiographic testing*

A welding inspector should have a general working knowledge of all these NDT methods, their applications, advantages and disadvantages.

NDT operators are examined to establish their level of skill, which is dependant on their knowledge and experience, in the same way as welders and welding inspectors are examined and tested to establish their level of skill.

Various examination schemes exist for this purpose throughout the world. In the UK the CSWIP and PCN examination schemes are those that are recognised most widely.

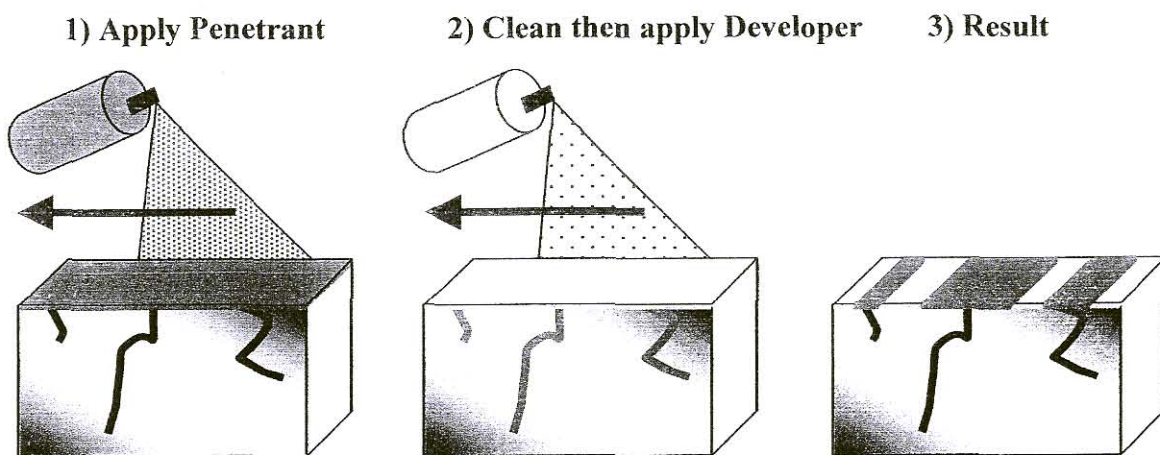
A good NDT operator has both knowledge and experience, however some of the above techniques are more reliant on these factors than others.

Penetrant Testing

× Basic Procedure

- 1) The component must be thoroughly cleaned and have a smooth surface finish
- 2) Penetrant is applied and allowed to dwell for a specified time. (Contact time)
- 3) Once the dwell or contact time has elapsed, the excess penetrant is removed by wiping with a clean lint free cloth, finally wiped with a soft paper towel moistened with liquid solvent. (Solvent wipe)
- 4) The developer is then applied, and any penetrant that has been drawn into any defect by capillary action will be now be drawn out by reverse capillary action
- 5) A close inspection is made to observe any indications (**bleed out**) in the developer
- 6) Post cleaning and protection

Method (Colour contrast, solvent removable)



× Advantage

- 1) Low operator skill level
- 2) Used on non-ferromagnetic
- 3) Low cost
- 4) Simple, cheap and easy to interpret
- 5) Portability

× Disadvantages

- 1) Careful surface preparation
- 2) Surface breaking flaws only
- 3) Not used on porous material
- 4) No permanent record
- 5) Hazardous chemicals

6) Temp. dependant
7) Can not retest indefinitely

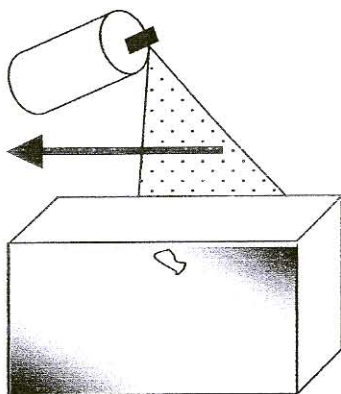
Magnetic Particle Testing

Basic Procedure

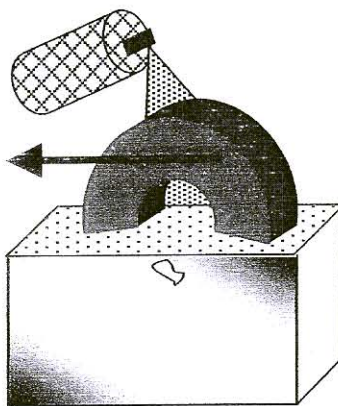
- 1) Test method for the detection of surface and sub-surface defects in **ferromagnetic** materials
- 2) Magnetic field induced in component.
(Permanent magnet, electromagnet (Y6 Yoke) or current flow (Prods))
- 3) Defects disrupt the magnetic flux
- 4) Defects revealed by applying ferromagnetic particles.
(Background contrast paint may be required)

Method

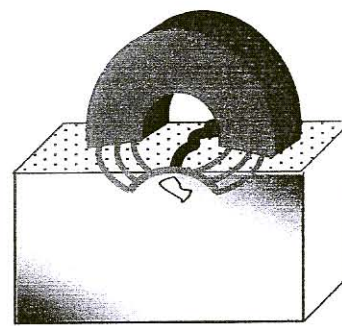
1) Apply contrast paint



2) Apply magnet & ink



3) Result



Advantage

- 1) Pre-cleaning not as critical as with DPI
- 2) Will detect some sub-surface defects
(1-2 mm)
- 3) Relatively low cost
- 4) Simple equipment
- 5) Possible to inspect through thin coatings

Disadvantages

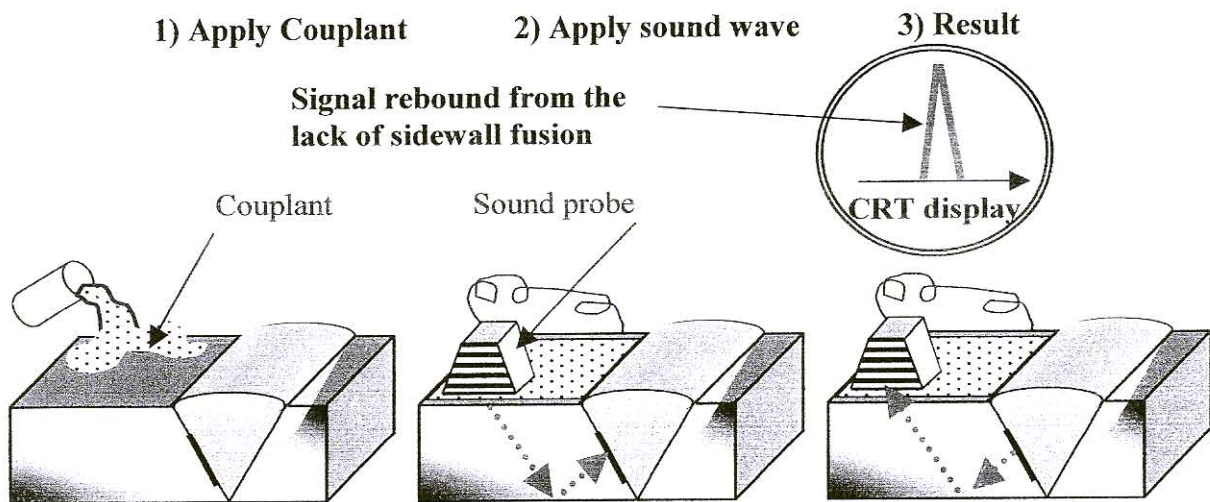
- 1) Ferromagnetic materials only
- 2) Demagnetisation may be required
- 3) Direct current flow may produce **Arc strikes**
- 4) No permanent record
- 5) Required to test in 2 directions

Ultrasonic Testing

Basic Procedure

- 1) Component must be thoroughly cleaned; this may involve light grinding to remove any spatter, pitting etc in order to obtain a smooth surface
- 2) Couplant is then applied to the test surface. (water, oil, grease etc.)
This enables the ultrasound to be transmitted from the probe into the component under test
- 3) A range of angled probes are used to examine the weld root region and fusion faces. (Ultrasound must strike the fusion faces or any discontinuities present in the weld at 90° in order to obtain the best reflection of ultrasound back to the probe for display on the cathode ray tube)

Method



Advantage

- 1) Can easily detect lack of sidewall fusion
- 2) Ferrous & Non - ferrous alloys
- 3) No major safety requirements
- 4) Portable with instant results
- 5) Able to detect and size sub-surface defects

6) High penetrant capability

Disadvantages

- 1) High operator skill level
- 2) Difficult to interpret
- 3) Requires calibration
- 4) No permanent record. (Unless automated)
- 5) Not easily applied to complex geometry

6) No good for porosity
 7) > 8mm due to dead zone

Radiographic Testing

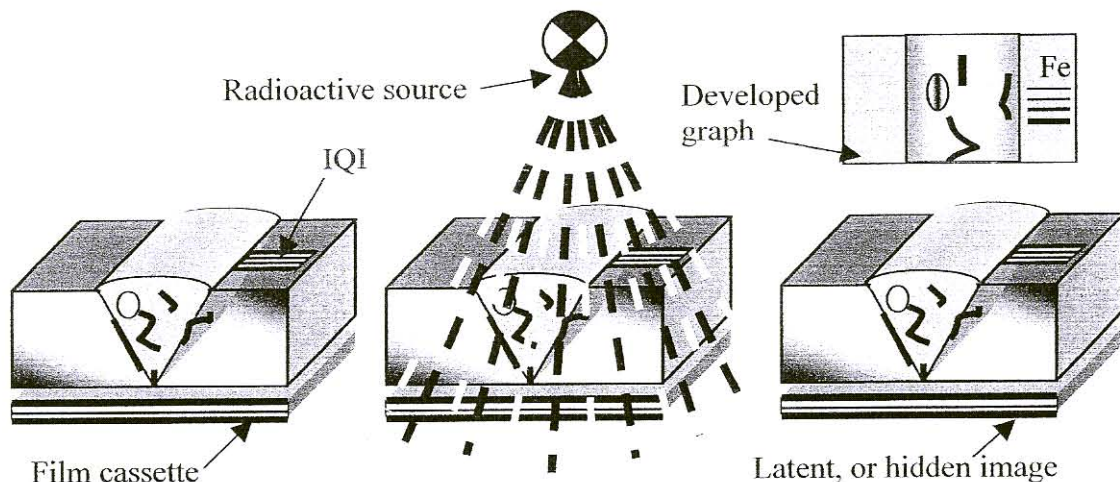
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Basic Procedure

- 1) X or Gamma radiation is imposed upon a test object
- 2) Radiation is transmitted in varying degrees dependant upon the density of the material through which it is travelling
- 3) Variations in transmission detected by photographic film, or fluorescent screens. (Film placed between lead screens then placed inside a cassette)
- 4) An IQI (image quality indicator) should always be placed **on top** of the specimen to record the sensitivity of the radiograph

Method

- a) Load film cassette b) Exposure to radiation c) Developed graph



XXX Advantage

- 1) Permanent record
- 2) Most materials can be tested
- 3) Detects internal flaws
- 4) Gives a direct image of flaws
- 5) Fluoroscopy can give real time imaging

6) Very good thickness penetration

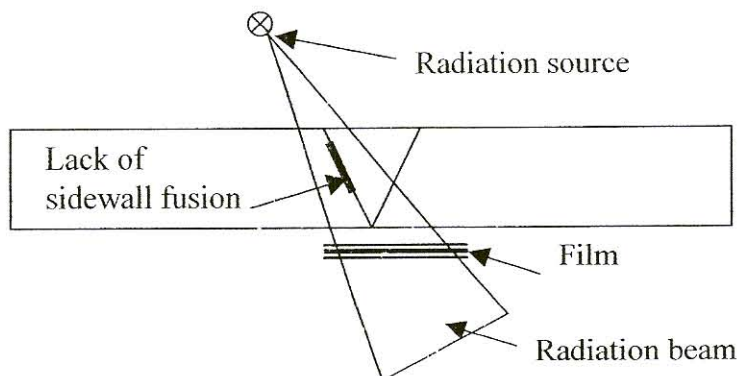
XXX Disadvantages

- 1) Skilled interpretation required
- 2) Access to both sides required
- 3) Sensitive to defect orientation (Possible to miss planar flaws)
- 4) Health hazard
- 5) High capital cost

Summary of Non Destructive Testing:

Discipline	Application	Advantages	Disadvantages
Penetrant Testing	Welds/Castings. Surface testing only. All materials can be tested. Colour contrast & florescent.	Low operator skill level	Highly clean the material
		All non porous material surfaces may be tested	Surface flaws only
		Low cost process	Extremely messy
		Simple equipment	No permanent record
Magnetic Particle Testing	Welds/Castings Ferrous metals only. Wet & Dry inks. Yokes. Permanent magnets and straight current AC/DC	Low operator skill level	Fe magnetic metals only
		Surface/Sub surface flaws	De-magnetise after use
		Relatively low cost	Can cause arc strikes using straight current technique
		Simple equipment	No permanent record
Ultra Sonic Testing	Welds/Castings. One side access. Un-favoured for large grained structured alloys. i.e. Austenitic S/S	Can more easily find lack of sidewall fusion defects	High operator skill level
		A wide variety of materials can be tested	Difficult to interpret
		No safety requirements	Requires calibration
		Portable with instant results	No permanent record
Radiographic Testing	Welds/Castings. Access from both sides is required. All materials. Gamma and X-ray sources of radiation used.	Permanent record of results	High operator skill level
		A wide variety of materials can be tested	Difficult to interpret
		Can assess penetration in small diameter, or line pipe	Cannot generally identify lack of sidewall fusion**
		Gamma ray is very portable	High safety requirements

** To identify **planar** or 2 dimensional defects such as lack of side wall fusion, or cracks etc, the orientation of the radiation beam must be in line with the orientation of the defect as shown below, hence if the radiation source is at the centre of the weld then **no indication** of lack of side wall fusion may be shown on the radiograph.



WIS 5 Section 15 Exercises:

- 1) List 5 advantages and 5 disadvantages of each NDT discipline?

Discipline	Advantages	Disadvantages
Penetrant Testing	1 _____	1 _____
	2 _____	2 _____
	3 _____	3 _____
	4 _____	4 _____
	5 _____	5 _____
Magnetic Particle Testing	1 _____	1 _____
	2 _____	2 _____
	3 _____	3 _____
	4 _____	4 _____
	5 _____	5 _____
Ultra Sonic Testing	1 _____	1 _____
	2 _____	2 _____
	3 _____	3 _____
	4 _____	4 _____
	5 _____	5 _____
Radiographic Testing	1 _____	1 _____
	2 _____	2 _____
	3 _____	3 _____
	4 _____	4 _____
	5 _____	5 _____

- 2) Briefly state the major limitation of the Radiographic NDT process in terms of the orientation and practical observation of internal planar imperfections?

- 3) Complete the basic procedure for the *Penetrant testing* method of NDT?

1. The component must be thoroughly cleaned with a smooth surface finish

2. _____

3. _____

4. _____

5. _____

6. _____

WIS 5 Welding Inspection

Section 16

Weld Repairs

Weld Repairs:

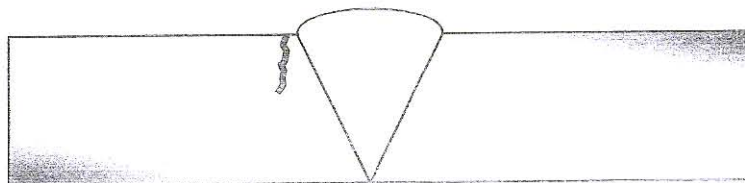
Weld repairs can be divided into two specific areas

- 1) Production repairs
- 2) In-service repairs

1) Production repairs:

The Welding Inspector or NDT operator will usually identify production repairs during the process of inspection or evaluation of NDT reports to the code or applied standard.

A typical defect in a weld HAZ is shown below:



Before any repair can commence the following issues may need to be fully considered.

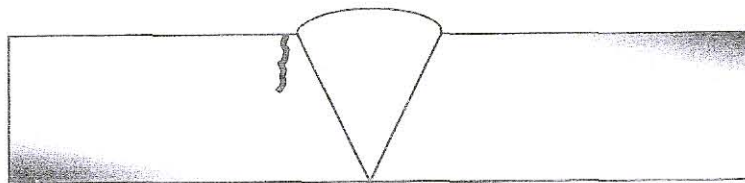
- a) *An analysis of the defect may need to be made by the QA department to discover the likely reason for the occurrence of the defect. (Material/Process or Skill related)*
- b) *A detailed assessment will need to be made to find out the full extremity of the defect. This may involve the use of a surface and/or sub surface NDT method. Once established the excavation site must be clearly identified and marked out.*
- c) *An excavation procedure will need to be produced, approved and executed.*
- d) *NDT should be used to provide confirmation of complete removal of the defect.*
- e) *A welding repair procedure will need to be drafted and approved. Welder approval to the approved repair procedure is normally carried out during the repair procedural approval.*
- f) *A method of NDT will have to be identified and a procedure prepared to ensure that a successful repair has been carried out.*
- g) *Final repair weld dressing and post repair procedures that need to be carried out i.e. PWHT. It may also be a requirement to carry out NDT after PWHT.*

a) Analysis:

As this defect has occurred in the HAZ the fault could be a problem with either the material or the welding procedure, however in this case, and if the approved procedure had been exactly followed then no blame can be apportioned to the skill of the welder.

b) Assessment:

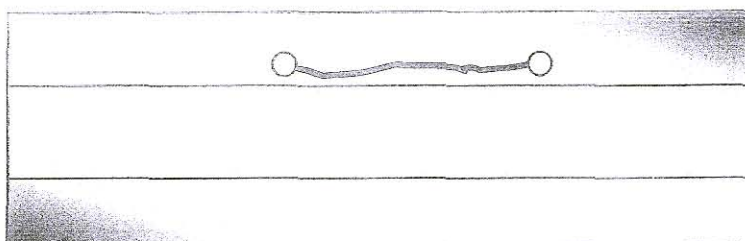
In this particular case as the defect is open to the *surface penetrant* testing may be used to *accurately gauge the length* of the crack and to *estimate the depth* of the crack. Once size and location has been determined it should be recorded identified and marked out.



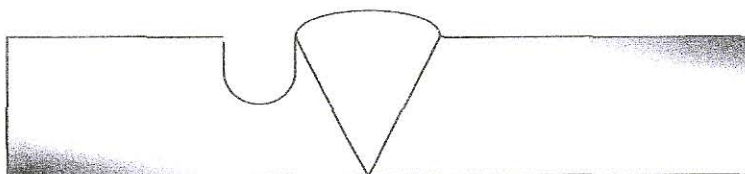
c) Excavation:

As this defect is a crack it is likely that the ends of the crack may be drilled to avoid any further propagation during excavation particularly if a thermal method of excavation is being used. If a mechanical method is used then the end of the excavation is made oval. The excavation procedure may also need approval particularly if it will affect the metallurgical structure of the component i.e. Arc Gouging.

Plan View of defect with drilled ends



Side View of defect excavation

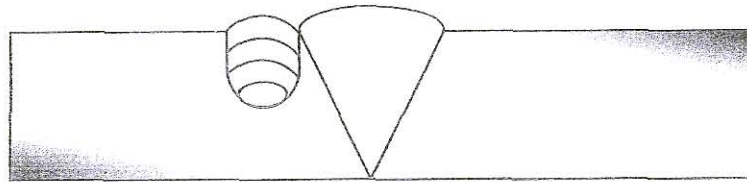


d) Confirmation of complete excavation:

At this stage NDT should be used to confirm the defect has been completely excavated from the area. In the case of the crack *Penetrant Testing* would most likely be used.

e) Re-welding of the excavation:

Prior to re-welding of the excavation a detailed weld procedure will need to be drafted and approved by the Welding Engineer. The procedural qualification is often carried out by the welder who is to be used on the repair and who then should become approved should the procedure become qualified.



f) NDT confirmation of successful repair:

After the excavation has been filled the *weldment* should then undergo a complete retest using NDT to check no further defects have been introduced during the repair.

g) Dressing, PWHT & final NDT (as applicable)

The repair weld may need to be dressed flush to avoid stress concentrations. NDT may also need to be further applied after any additional *Post Weld Heat Treatments*. (PWHT)

2) In service repairs:

Most in service repairs can be of a very complex nature as the component is very likely to be in a different welding position and conditions that existed during production. It may also have been in contact with toxic or combustible fluids hence a permit to work will need to be sought prior to any work being carried out. The repair welding procedure may look very different to the original production procedure due to changes in these elements.

Other factors may also be taken into consideration such as the effect of heat on any surrounding areas of the component i.e. electrical components or materials that may become damaged by the repair procedure. This may also include difficulty in carrying out any required pre or post welding heat treatments and a possible restriction of access to the area to be repaired. For large fabrications it is likely that the repair must also take place on site and without a shut down of operations, which may produce many other elements that need to be considered. Repair of *in service defects/failures* may require consideration of these and many other factors and as such are generally considered much more complex than production repairs.

WIS 5 Section 16 Exercises:

- 1) List the elements that may need to be considered before commencing a repair?

1. Analysis of the defect to discover the reason for the occurrence

2. _____

3. _____

4. _____

5. _____

6. _____

7. _____

8. _____

9. _____

10. _____

- 2) List any documents that any *Welding Inspector* may be required to refer to before, during or after any weld repair?

WIS 5 Welding Inspection

Section 17

Residual Stress and Distortion

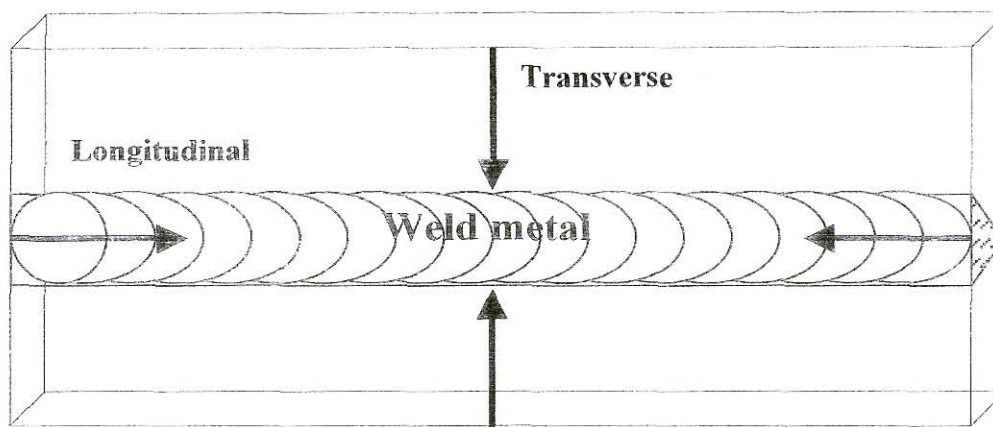
Residual Stress and Distortion:

Residual stresses are defined as those stresses remaining inside a material after a process has been carried out. The process used is welding, and the stresses are caused by the heat of welding producing local expansion and contraction to take place. If a block of metal was heated uniformly to a temperature and then cooled under the same conditions no stresses would be left in the block, as expansion and contraction is uniform and equal.

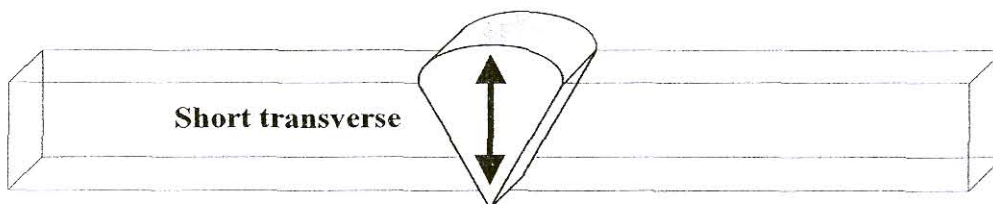
Welding causes un-uniform heating and cooling conditions to exist and are compounded by the fact that the material is increasingly restricted from freedom of movement as the welder moves along the welded seam. The stresses that remain in the structure after welding are called **residual stresses**. Residual stresses may compound with applied stresses to cause early failure, and may be reduced after welding by heat treatments.

The stresses caused by local expansion and contraction strain can be a very complex pattern in a welded construction, however we can say that they have three basic directions.

Plan View of a welded plate.



End View of a welded plate.

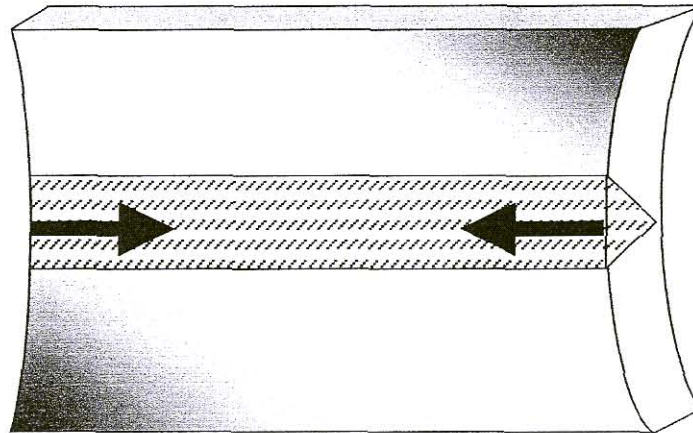


One effect of residual welding stress is to change the materials original shape producing distortion. Distortion during welding operations is mainly caused by local heating and cooling and thus local movement of material through local expansion and contraction. This effect can render a product useless unless it is controlled.

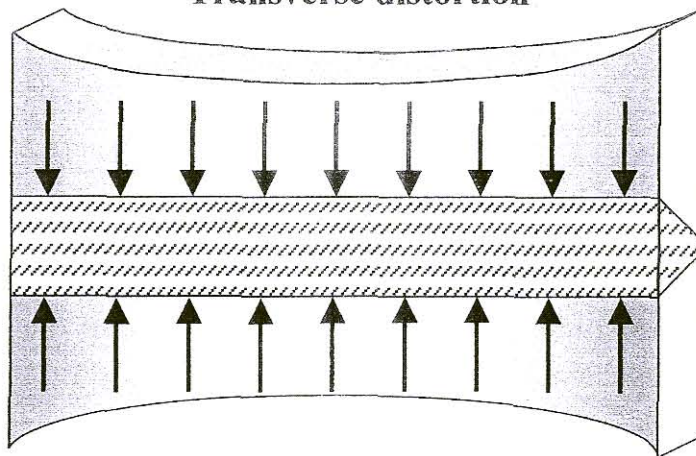
The degree of distortion occurring is highly dependant on a number of key elements including the materials *co-efficient of expansion* and *heat input*, though the materials natural *rigidity* and *thickness* can also play an important part in minimising this effect.

Distortion, like the overall pattern of *residual stresses* can be very *complex*, however we can show the three basic directions of distortion shown *exaggerated* as follows:

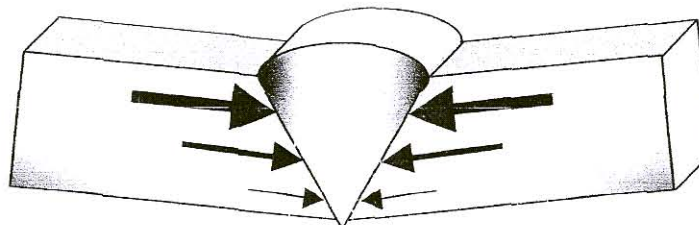
Longitudinal distortion



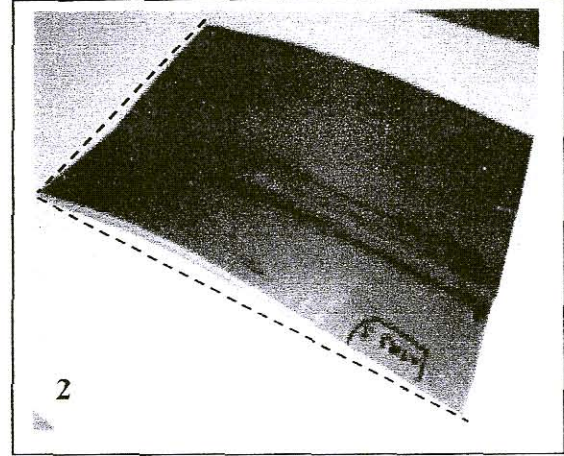
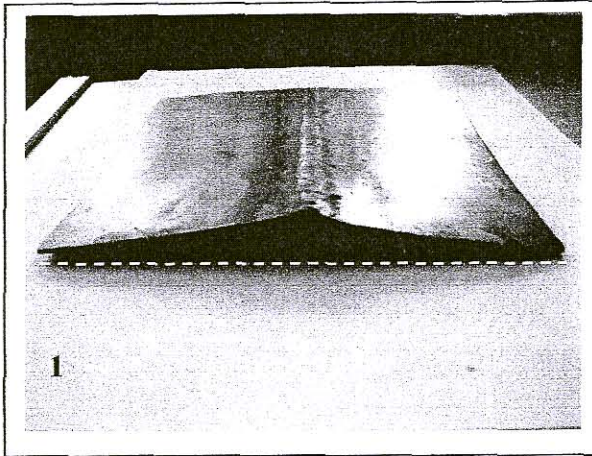
Transverse distortion



Angular distortion

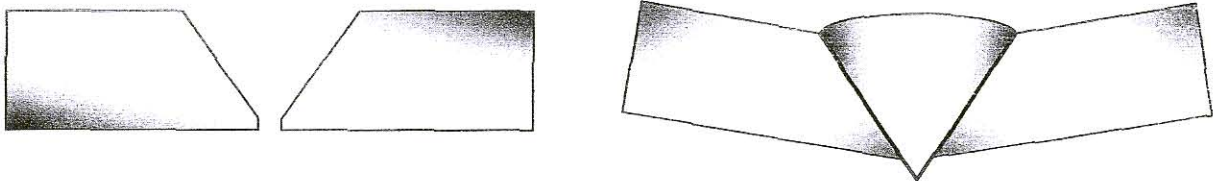


Examples of how insufficient rigidity in welded sheet metal can allow distortion to occur in several directions. 1) A gas welded sheet butt joint. 2) A stainless steel butt joint.

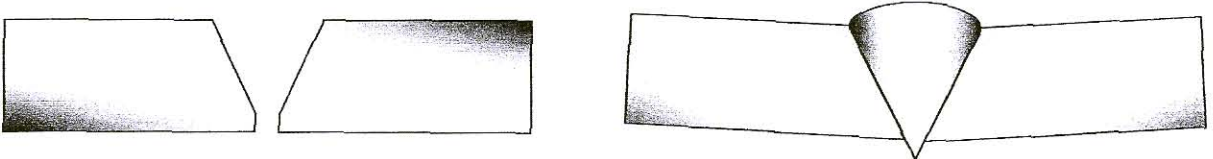


Any increase in total **volume** of weld metal will increase the total **heat input** into a joint, increasing local **expansion and contraction** in the HAZ and directly increasing the visible effect of **distortion**. Extending the included angle of a weld preparation will increase in the volume of contracting weld metal. It would also follow that reducing the volume will reduce the heat input and also the level of contraction. As the majority of weld volume and thus contraction is at the top of the weld preparation this effect and that of reducing the included angle in a single sided preparations is **shown below**. As the **welding process** determines the value of the included angle any changes may **seriously effect the welding process operation**.

Preparation angle of 60° - 75°



Preparation angle of 40° - 60°



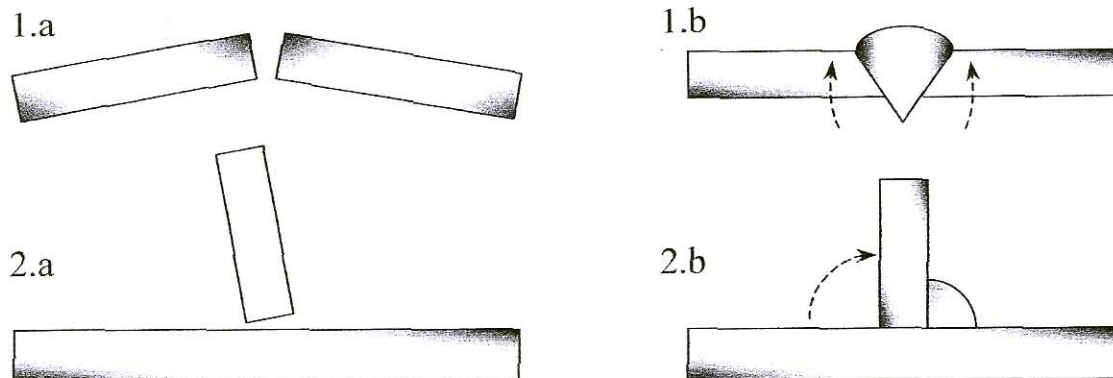
Preparation angle of 0° - 5°



To counteract the effects of expansion contraction and distortion we can carry out one of the following techniques:

Offsetting:

Offsetting means to offset the plates to a pre-determined angle as in 1&2 a, then allowing distortion to take place to the final position of the weld, as shown in 1&2 b, below.

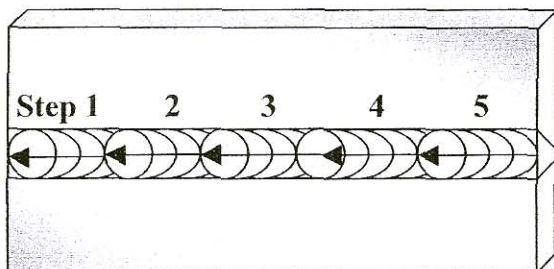


The amount of offsetting required is generally a function of trial & error, but if there are many numbers of components to produce it can be an economical method of controlling distortion.

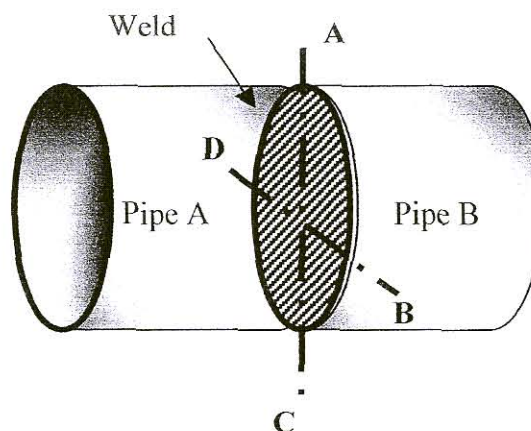
Back-step Welding and Balance Welding: (Sequence Welding)

These methods of distortion control use a specific technique, or *welding sequence* to control the effects of distortion. Examples are shown below:

Back-step welding a plate butt weld



Balance welding of a pipe butt root

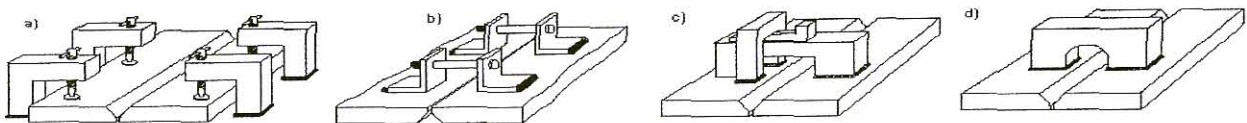


Weld 1 from A – B
Weld 3 from B – C

Weld 2 from C – D
Weld 4 from D – A

Clamping Jigging and Tacking:

In clamping and jigging, the materials to be welded are prevented from moving by the clamp or jig. The advantage of using a jig is that elements in a fabrication can be precisely located in the position to be welded and can be a very time saving method of manufacturing high volume products. On most occasions the components are accurately positioned by the jig and then tacked in position to prevent movement, then the jig is removed to allow full access for welding. The use of **clamps, jigs, strong backs, bridging pieces, and tack welds** will severely restrict any movement of material, and so reduce distortion, this however will also increase the maximum amount of residual stresses. Pictorial examples of some of these methods are shown below:



Summary of Residual Stresses & Distortion:

- 1) Residual stresses are locked in elastic strain, which is caused by local expansion & contraction in the weld area.
- 2) Residual stresses should be reduced from structures after welding as they may cause Stress Corrosion Cracking to occur, and can compound with applied stresses. They may also affect dimensional stability when machining a welded component.
- 3) The amount of contraction is controlled by: The volume of weld metal in the joint, the thickness, heat input, joint design, and the coefficient of conduction.
- 4) Offsetting may be used to finalise the position of the joint.
- 5) If plates or pipes are prevented from moving by tacking, clamping or jigging etc. then residual stresses that remain will be of a higher magnitude.
- 6) The movement caused by welding related stresses is called **distortion**.
Oxy-fuel gas Spot Heating may be used in attempting to straighten distorted objects, though this will have limited success if the distortion is severe.
- 7) The directions of contract ional stresses and distortion are very complex as is the amount and type of final distortion, however we can say that there are 3 directions:
a) Longitudinal b) Transverse c) Short transverse
- 8) A high percentage of residual stresses can be removed by **heat treatments**.
Ultrasound has also been used in the stress relieving of fabrications.
- 9) The **peening** of weld faces (With the use pneumatic needle guns) will only re-distribute residual stresses, by placing the weld face in compression.

WIS 5 Section 17 Exercises:

- 1) Briefly define residual welding stress?

- 2) List 2 further direction s of distortion?

1. Longitudinal

2. _____

3. _____

- 3) List 4 other methods that may be use in controlling the effects of distortion?

1. Tacking

2. _____

3. _____

4. _____

5. _____

- 4) List 2 other material/welding process related elements related to distortion?

1. Arc Energy Input

2. _____

3. _____

- 5) List 2 other problems that may be expected if these stresses are not removed?

1. Dimensional instability on machining

2. _____

3. _____

WIS 5 Welding Inspection

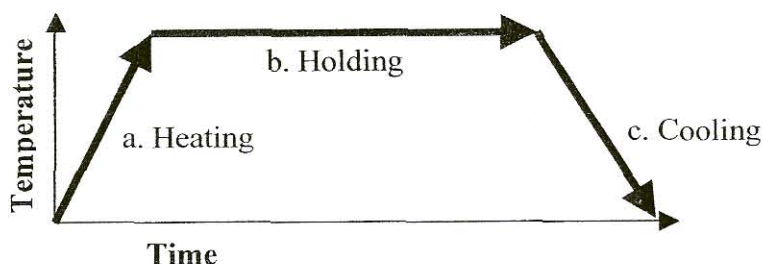
Section 18

Heat Treatment of Steels

Heat Treatment of Steels:

All heat treatments are basically cycles of three elements, which are:

- a) Heating b) Holding or Soaking c) Cooling



We use heat treatments to change properties of metal, or as a method of controlling formation of structures, or expansion/contractual forces during welding.

In heat treating metals and alloys there are many elements for the welding inspector to check that may be of great importance, such as the rate of climb and any hold points in the heating cycle. The holding or soaking time is generally calculated at 1 hour for every 25mm of thickness, but this can vary. Heat treatments that are briefly covered in this section are as follows:

- | | |
|---------------------|----------------|
| 1) Annealing | 2) Normalising |
| 3) Hardening | 4) Tempering |
| 5) Stress relieving | 6) Pre-heating |

The methods/sources that may be used to apply heat to a fabrication may include:

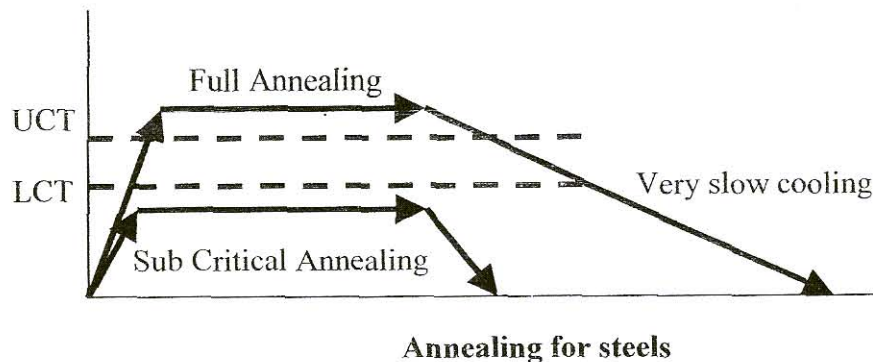
- a) Flame burners/heaters (Propane etc.) **Preheating**
b) Electric resistance heating blankets. **Pre-heating & PWHT**
c) Furnaces. **Annealing, Normalising, Hardening, Tempering**

The tools that an inspector may use to measure the temperatures of furnaces and heated materials may include.

- a) Temperature indicating crayons (Tempil sticks). **Pre-heating**
b) Thermo-couples. **All heat treatments.**
c) Pyrometers (Optical, Resistance, Radiation.). **Furnace heat treatments**
d) Segar cones. **Furnace heat treatments**

The welding inspector should observe that all heat treatments are carried out as specified and make records of all parameters. This is a critical part of the duties of a welding inspector who should also ensure that all documents are retained within the quality files.

1) Annealing



Annealing is a heat treatment process that may be carried out on steels, and most metals that have been worked hardened or strengthened by an alloying precipitant, to regain the **softness and ductility**. In the latter case we generally refer to solution annealing. In work hardened non-ferrous metals, annealing is used to re-crystallise work-hardened grains. When annealing most work hardened non-ferrous alloys the cooling rate is not always critical, and cooling may be rapid without forming any hardened structures. In steels we can carry out 2 basic kinds of annealing:

- a) **Full Annealing (Including Solution Annealing)**
- b) **Sub Critical Annealing**

In **full annealing** of steels the steel is heated above its UCT (upper critical temperature) and allowed to cool very slowly in a furnace. This slow cooling will result in a degree of grain growth, which produces a soft and ductile structure. There are no temperatures that can be quoted for annealing steels, as this will depend entirely upon the carbon content of the steel.

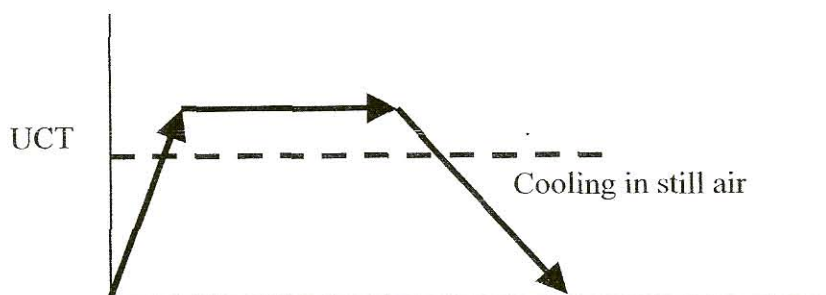
The UCT range of Plain Carbon Steels ranges between **910 – 723 °C**, however the temperature is mostly taken to **50 °C** above the calculated UCT to allow for any inaccuracies in the temperature measuring device. Plain carbon steel of carbon content of 0.2% would have an annealing temperature in the region of **850 - 950 °C**

The **solution annealing** of some metallic alloys may require a rapid cooling rate.

In **sub critical annealing** the steel is heated to temperatures well below the lower critical temperature (**723 °C**). This type of annealing is similar to that used with non-ferrous metals as it is only the deformed ferritic grains that can be re-crystallised at these lower temperatures.

The term **annealing** generally means to bring a metal, or alloy, to its **softest and most ductile natural condition**. In steels this also means a reduction in toughness, as the resultant large grain structure shows very low impact strength.

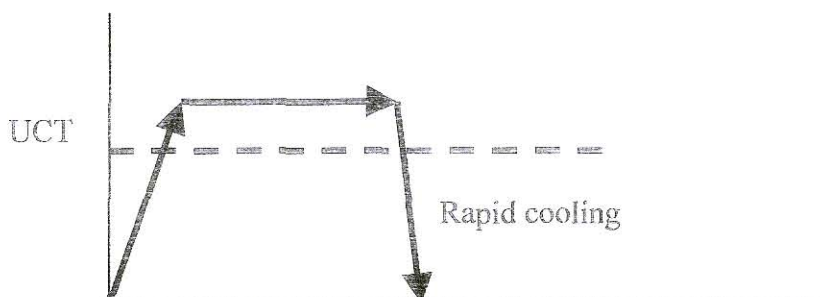
2) Normalising



Normalising is a heat treatment process that is generally used for steels. The temperature climb and holding may be exactly the same as for annealing, however the steel is removed from the furnace after the soaking period to be allowed to cool in still air.

This produces a much finer grain structure than annealing and although the softness and ductility is reduced, the strength and hardness is increased. Far more importantly the **toughness**, or impact strength is vastly improved.

3) Hardening



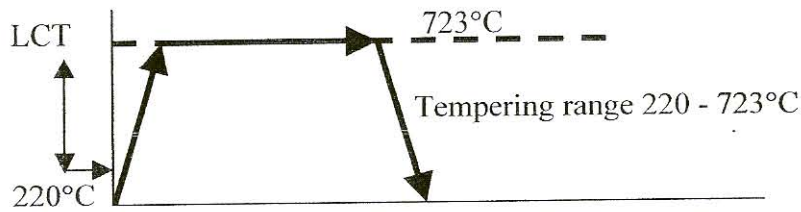
In the thermal hardening of steels the alloy must be taken above its UCT as with all the heat treatment processes discussed thus far, and soaked for the same period. The major difference is in the cooling cycle where cooling is generally rapid.

For plain carbon steel, the steel must have a sufficiently high carbon content to be hardened by thermal treatment, which is generally considered as $> 0.3\%$ carbon. Alloy steels containing carbon contents below 0.1% with added Mn. Cr. Mo. or Ni. Etc. can be made much harder by thermal heat treatment.

Some steels are specially designed to produce hardness even at very slow rates of cooling, and are included in a group of steels called Air Hardening Steels.

The cooling media for quenching steels is very important; as if the steel is cooled too quickly then the thermal shock may be too rapid and cause cracking to occur in the steel. Brine is considered to be the fastest cooling media followed by water and then oil.

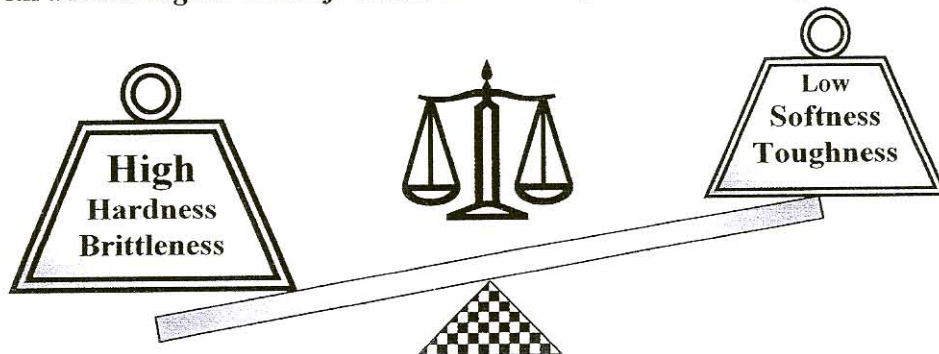
4) Tempering



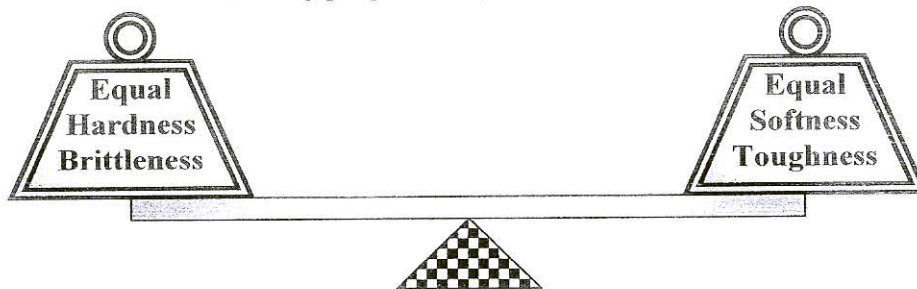
Fe steel temper colours:

300°C
280°C
260°C
240°C
220°C

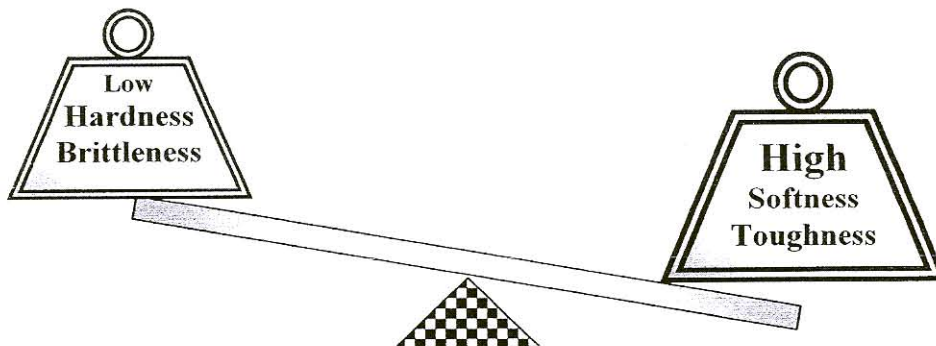
Tempering is a *sub critical heat treatment process* that can only be used after thermal hardening has first been carried out, as the process of thermal hardening will leave some steels with a much *higher level of relative hardness*, but also in a *very brittle* condition.



Balance of properties after Thermal Hardening



Balance of properties after a temper at 350 °C



Balance of properties after a temper at 720 °C

The softness, and far more importantly the toughness, is of very low values after thermal hardening, and the term **temper** really means **to balance**. When tempering steel we **re-balance** the properties of excessive hardness and brittleness by decreasing the hardness and increasing the level of toughness.

The process of tempering the hardness commences measurably at around 220°C and continues up to the LCT, or 723°C. At this point most of the extra hardness produced by thermal hardening has been removed, or fully tempered, but the fine grain structure produced by the hardening process will remain, giving the steel good toughness and strength. This is the mechanism used to give good toughness, and strength to Q/T steels, which are normally tempered from between 550 – 700 °C.

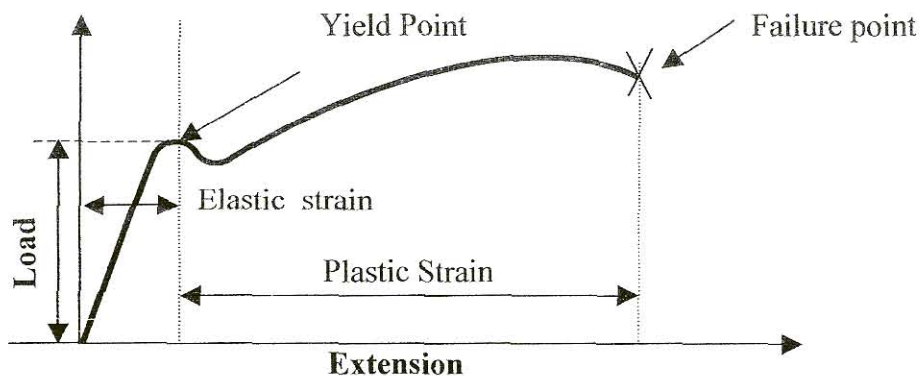
5) Stress relieving or PWHT

The purpose of stress relieving is to relieve internal elastic stress that has become trapped inside the weld during welding. The procedure of heat, hold and cool is the same as all other heat treatments however special heating curves are required when stress relieving some types of steels, particularly **Creep Resistant Steels**.

During stress relieving, steels may be heated from between 200-950 °C, although most stress relieving is carried out on steels between the temperatures of 550 – 700 °C, depending on steel type and amount of stress to be relieved. To understand what happens during stress relieving there are a number of terms that require to be defined:

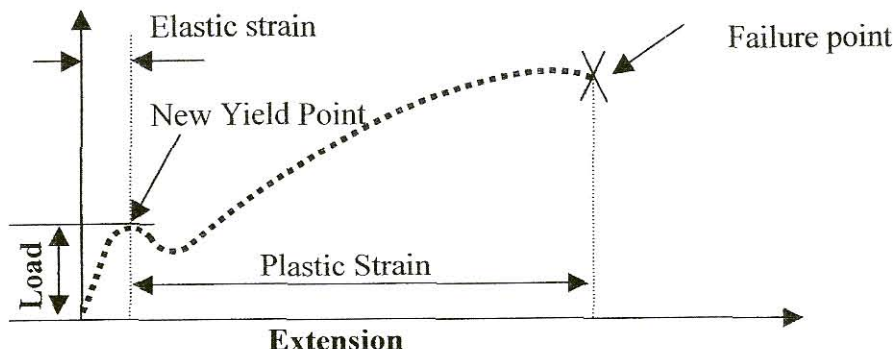
Yield Point (Re)

This is the point where steel can no longer support elastic strain and becomes plastically deformed i.e. plastic strain occurs. This means that the steel will no longer return to its original dimensions. The residual stresses that are contained within steels after welding are all elastic, with the remaining stresses having been absorbed by plastic movement of the steel (Distortion). The stress/strain diagram of annealed low carbon steel below shows this point:



When steel is heated the yield point is suppressed, which means that the elastic strain shown above will now start to become plastic strain.

The higher the temperature, then generally the more elastic strain will be converted to plastic strain, or plastic movement. It is generally accepted that up to 90% of residual welding stresses can be plastically relieved during this process. This change is shown diagrammatically below:



When the temperature is returned to ambient temperatures, the yield point returns to practically the same position as at the start of the heat treatment.

6) Pre-heating

We can preheat metals and alloys when welding for a number of reasons. Primarily we use most pre-heats to achieve one or more of the following:

- 1) To control the structure of the weld metal and HAZ on cooling.
- 2) To improve the diffusion of gas molecules through an atomic structure.
- 3) To control the effects of expansion and contraction.

We can control the formation of un-desirable microstructures that are produced from rapid cooling of certain types of steel. **Martensite** is produced by the entrapment of carbon in solution at temperatures **below 300 °C**. The function of a pre-heat with susceptible steels is thus 2 fold, the first being the suppression of ***martensite*** formation by delaying the cooling rate, and secondly allowing the trapped hydrogen gas to diffuse out of the HAZ, or weld metal area back to the atmosphere. We may also control the effect of expansion and contraction in welds.

Summary:

We use heat treatments to change, or control the *final properties of welded joints and fabrications*. All heat treatments are cycles of 3 elements, **heating, holding and cooling**.

The welding inspector should carefully monitor the heat treatment procedure, its method of application, and measuring system. All documents and graphs relating to heat treatments should be submitted to the Senior Inspector in the Q/C department to be logged in the fabrication quality document files.

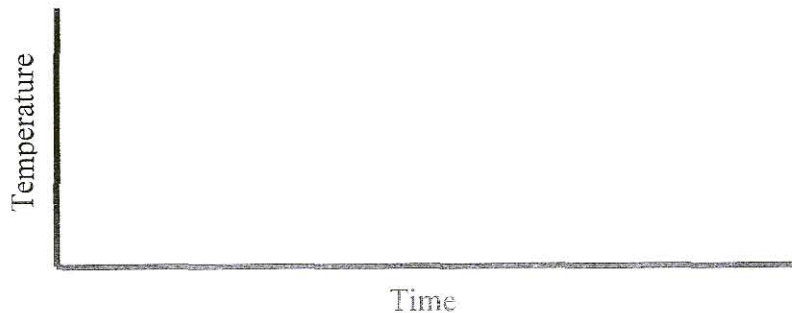
Summary of Heat Treatments of Steels: xxx

Treatment	Method	Uses
Annealing	The steel is heated above its upper critical temperature and soaked for 1 hour for every 25mm of thickness. The furnace is then turned off and the steel remains in the furnace to cool. This produces a large or coarse grain structure that is soft and ductile but has very low toughness.	Used to make steels soft and ductile.
Normalising	The steel is heated above its upper critical temperature as in annealing and soaked for 1 hour for every 25mm of thickness. Once the soaking time has elapsed the steel is removed from the furnace to cool in still air. Produces a smaller, or fine grain structure that has high toughness and strength, though ductility is lower than annealed steel.	Used to make steels tougher and stronger
Hardening	The steel is heated above its upper critical temperature as in annealing and soaked for 1 hour for every 25mm of thickness. Once the soaking time has elapsed the steel is removed from the furnace to quench in a cooling medium. Produces a fine grain <i>martensitic</i> structure that has very high hardness and strength, though ductility is almost zero, with very low toughness.	Used to make medium or high plain carbon and most low alloy steels harder.
Tempering	The steel is re-heated after hardening, and the balance of hardness to toughness is adjusted as the temperature is increased from 220° – 723 °C At 723 °C all <i>martensite</i> has been tempered removing the brittleness and returning the toughness and some ductility. The steel has high tensile strength due to the retained fine grain structure if not heated above 723 °C	Used to rebalance the properties of thermally hardened steels.
Stress Relieving	The steel is heated to a temperature dependant on the type of steel being heat-treated. Plastic flow of stresses increases as the temperature rises relieving the locked in elastic stresses.	Used after welding to relieve the trapped elastic stresses caused through expansion and contraction forces.
Pre-Heating	The steel is heated to a temperature dependant on the type of steel being heat treated, but normally less than 350 °C This suppresses the formation of <i>martensite</i> and allows time/temperature for diffusion of H ₂	Used to control the formation of H ₂ cracks. Also used to control the effects of expansion and contraction forces.

WIS 5 Section 18 Exercises:

- 1) Briefly define a heat treatment using a diagram to indicate the basic stages?

Area for basic line diagram



- 2) List 2 further methods of applying heat to a metal?

1. Flame burners/heaters

2. _____

3. _____

- 3) List 4 other methods that may be used to measure temperature?

1. Temperature indicating crayons (Tempil sticks)

2. _____

3. _____

4. _____

5. _____

Insert the missing information in the table given below?

Treatment	Method	Uses
Annealing	The steel is heated above its upper critical temperature and soaked for 1 hour for every 25mm of thickness. The furnace is then turned off and the steel remains in the furnace to cool. This produces a large or coarse grain structure that is soft and ductile but has very low toughness.	
.....	The steel is heated above its upper critical temperature as in annealing and soaked for 1 hour for every 25mm of thickness. Once the soaking time has elapsed the steel is removed from the furnace to cool in still air. Produces a smaller, or fine grain structure that has high toughness and strength, though ductility is lower than annealed steel.	Used to make steels tougher and stronger
Hardening	The steel is heated above its upper critical temperature as in annealing and soaked for 1 hour for every 25mm of thickness. Once the soaking time has elapsed the steel is removed from the furnace to quench in a cooling medium. Produces a fine grain <i>martensitic</i> structure that has very high hardness and strength, though ductility is almost zero, with very low toughness.	
.....	The steel is re-heated after hardening, and the balance of hardness to toughness is adjusted as the temperature is increased from 220° – 723 °C At 723 °C all <i>martensite</i> has been tempered removing the brittleness and returning the toughness and some ductility. The steel has high tensile strength due to the retained fine grain structure if not heated above 723 °C	Used to rebalance the properties of thermally hardened steels.
Stress Relieving		Used after welding to relieve the trapped elastic stresses caused through expansion and contraction forces.
Pre-Heating	The steel is heated to a temperature dependant on the type of steel being heat treated, but normally less than 350 °C This suppresses the formation of <i>martensite</i> and allows time/temperature for diffusion of H ₂	

WIS 5 Welding Inspection

Section 19

Oxy Fuel Gas Welding Brazing and Bronze Welding

Oxy Fuel Gas Welding, Brazing & Braze/Bronze Welding:

The oxy fuel gas heating method has been used for many decades as a portable means of applying heat for many operations directly linked to welding. These may include:

- | | |
|---------------------------------------|---------------------------------------|
| 1) Pre-heating (Section 18) | 2) PWHT (Section 18) |
| 3) Cutting (Section 20) | 4) Soldering (N/A) |
| 5) Brazing (Section 19) | 6) Bronze welding (Section 19) |
| 7) Fusion welding (Section 19) | 8) Straightening (Section 17) |

3	GAS WELDING
31	Oxy-fuel gas welding
311	Oxy-acetylene welding
313	Oxy-hydrogen welding
32	Air fuel gas welding

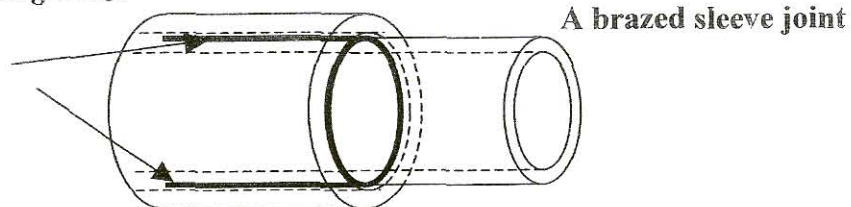
9	BRAZING, SOLDERING & BRAZE WELDING
91	Brazing
912	Flame brazing
94	Soldering
942	Flame soldering
97	Braze welding
971	Gas braze welding

The *essential differences* between the processes of *Soldering, Brazing and Bronze Welding* are summarised below:

Soldering: Mechanical bond with slight surface alloying. With **M. P. < 500 °C**
As soldering is used for wires/thin gauge it is not considered here.

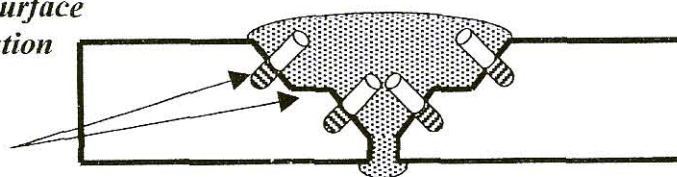
Brazing: Mechanical bond with slight surface alloying. With **M. P. > 500 °C**
The weld is formed as a result of a capillary action i.e. Sleeve joint.
Strength of the joint is very dependent upon the bond *surface area*.
This process contains all the “*Silver Brazing*” alloys, thus the use of the term “*Silver Solders*” is an *incorrect* use of *terminology*.

Capillary action drawing braze metal into the joint



Braze Welding: Mechanical bond with slight surface alloying **M.P. > 500 °C**
The formed weld may be either a butt or fillet weld, but strength of the joint is again very dependent upon bond surface area. It is often termed *bronze welding*. **A braze or bronze welded butt joint**

Increasing the joint surface area through preparation angles and studding.



The strength of the joint and hence the success of any soldering/brazing or bronze welding operation is highly dependant upon surface preparation and correct cleaning, both prior too, and during the operation, mainly in the removal of surface oxides. Cleaning prior to the operation will often be mechanical i.e. light grinding wire brushing or use of fine emery papers and a final solvent clean, whilst cleaning during the operation is generally carried out chemically by the action of a flux.

The equipment for gas welding/brazing operations generally consists of 2 cylinders, 1 containing acetylene and 1 containing oxygen. Acetylene gas is very unstable and will self detonate at very low pressure, hence it becomes a very dangerous gas to store in a cylinder under pressure. To enable storage to be achieved acetylene is dissolved in liquid acetone, which can absorb around 25 times its own volume of acetylene gas. The acetone is then absorbed in a charcoal and kapok mass, this makes the gas much more stable to store. For this reason the cylinder should always be used in the vertical position, as liquid acetone will be expelled from the blowpipe if it is not used vertically. This will have a similar effect to a flame-thrower, and is a very dangerous situation.

If transported, or stored horizontally the cylinder should be placed vertically and not used for a minimum of 1 hour to avoid this effect. Oxygen may be supplied at pressures of up to 200 bar or 3,000 PSI and must therefore be treated with the greatest respect. Should the valve seat of an oxygen cylinder become fractured by sudden impact the results would be catastrophic, with a very high probability of resultant death for any persons in the immediate vicinity. Great care should therefore be exercised to ensure that all pressurised cylinder gases are stored and used safely and securely.

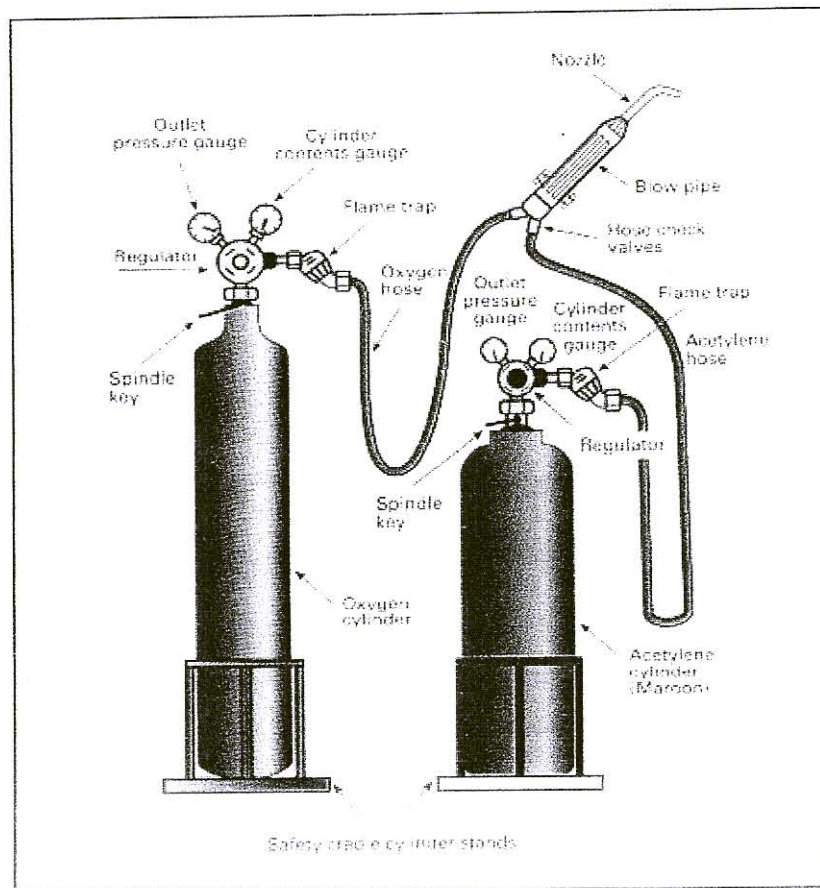
The use of non-propriety grades of brass may contain a high % of Cu, which may form explosive compounds on contact with pressurised acetylene.

Any contact of compressed oxygen gas with any oils or grease is extremely likely to cause serious spontaneous combustion to occur.

Key gas usage safety factors that must be observed:

- a) Cylinders must be secured in vertical position
- b) Only correct fittings must be used for all connections
- c) Oil or grease must not be used on any connections
- d) Left-handed threads must be used for fuel gasses
- e) Colour coding of hoses must be adhered to
- f) Flash back arrestors must be used on oxygen and fuel gas supplies
- g) One-way valves must be used on each hose/torch connection
- h) The correct start up and shutdown procedure must be followed
- i) All equipment must be thoroughly leak tested (Using a soapy liquid solution)
- j) Always keep the cylinder key in the acetylene cylinder

A typical set of oxy-acetylene welding equipment is shown below:



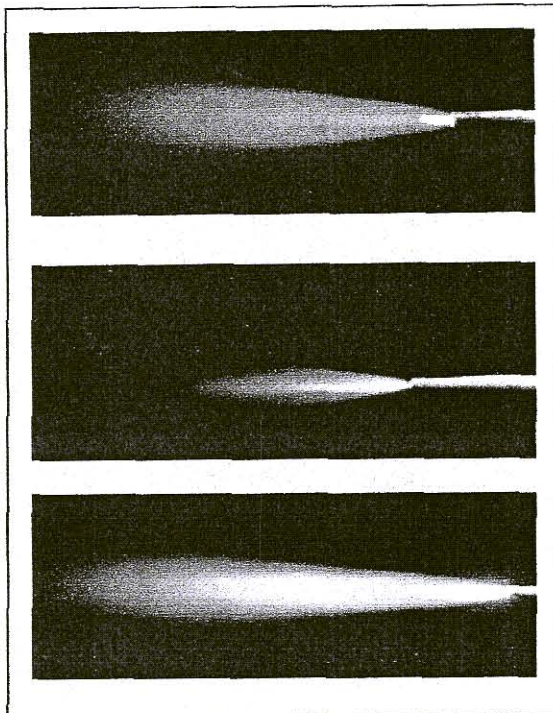
Oxy – Acetylene Fusion Welding:

The flame temperature of Acetylene combusted in air is 2,300 °C, whilst the flame temperature combusted with oxygen is 3,200 °C, which is the highest temperature achievable from the normal combustion of industrial gases. This temperature is higher than the melting point of all the metals with the exception of **tungsten**, which has a melting point of over 3,410 °C. During all Welding, Brazing and Braze/Bronze welding operations it is required that surface oxides need to be removed from either the molten pool in fusion welding, or the joint surface area of a brazed or braze/bronze welded joint.

In the arc welding processes the heat of the arc is generally high enough to melt the surface oxides of the metal with the exception of the TIG welding of **aluminium** as the surface oxide called alumina (aluminium oxide) has a melting point of over 2000 °C. For this reason we often need to use a flux when gas welding many ferrous and non-ferrous alloys, such as the fusion welding of **stainless steels** and aluminium alloys. When welding **plain carbon steels** a flux is not required as the melting point of iron oxide is below that of the alloy.

Oxy – Acetylene Flame Types

Uses



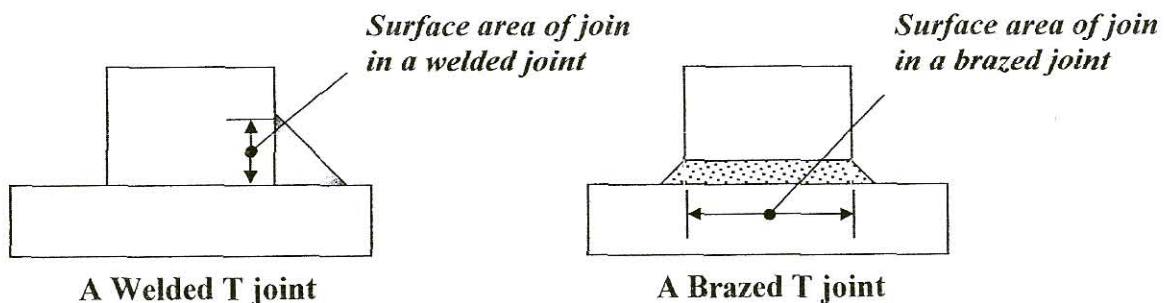
A *neutral flame* used for the fusion welding of most metals and alloys, including all types of steels. (This flame setting is also used for oxy/acetylene gas cutting pre-heat flame but with a different nozzle type)

An *oxidising flame* used mainly for bronze welding. (Produces a Zinc Oxide layer on the surface, reducing any further *volatilisation* of harmful zinc fume)

A *carburising flame* used mainly for hard facing, and the fusion welding and brazing of aluminium and its alloys.

Oxy - Fuel Gas Brazing and Bronze Welding:

Oxy fuel gas welding may be used very successfully as a heat source for brazing and bronze welding, the difference between the terms being that the term **brazing** involves a capillary action of some kind within the joint, and **bronze welding** is simply a shape of weld, which is generally a fillet or butt weld, made of a bronze, or brass alloy. Other less expensive fuel gases may be used as the temperature required is not as high as that required in fusion welding. A 9% Nickel bronze filler wire is mainly used for braze welding repairs of cast irons. (Nickel bronze is a closer colour match and also has a tensile strength double that of low carbon steels) Aluminium and aluminium alloys may be brazed using an Oxy-Acetylene flame heat source, with aluminium braze filler metal containing approximately 15% silicon. In the correct application, a brazed, or bronze welded joint may be much stronger than any fusion-welded joint, as the surface area of joining is much higher, as is shown below:



WIS 5 Section 19 Exercises:

- 1) Briefly describe the major differences between Soldering Brazing and Braze/Bronze welding?

- 2) List 9 other safety precautions to be strictly observed when working with the oxy-acetylene processes?

1. Cylinders must be "secured" in the vertical position

2.

3.

4.

5.

6.

7.

8.

9.

10.

- 3) List 3 types of oxy-acetylene flame and a use for each type?

Flame type	Use/Application
1.	
2.	
3.	

WIS 5 Welding Inspection

Section 20

Thermal Cutting Processes

Thermal Cutting/Gouging Processes:

All thermal cutting processes that we use in fabrication must satisfy 2 major functions to be successfully used as a cutting/gouging process.

- 1) **A temperature** capable of melting the materials being cut
- 2) **A velocity** capable of removing the molten metal and/or oxides from the cut

8	CUTTING & GOUGING
81	Flame cutting
82	Arc cutting
821	Air Arc cutting
822	Oxygen Arc cutting
83	Plasma cutting
84	Laser cutting
86	Flame gouging
87	Arc Gouging
871	Air-Arc Gouging (Using Carbon Electrodes)
872	Oxy-Arc gouging
88	Plasma gouging

Oxy Fuel Gas Flame Cutting (81) Flame Gouging (86)

In oxy-fuel gas cutting the temperature is achieved by the exothermic reaction of iron at its ignition temperature and pure oxygen. The product of iron oxide is removed from the cut edge, or **kerf** by the velocity of the oxygen gas jet. Thus in oxy-fuel gas cutting we do not need to melt the steel, but more simply heated it until it reaches its **ignition temperature**. (At around 1100 °C or a **bright cherry red** colour) At this temperature the iron will react with pure oxygen producing an exothermic chemical reaction, the product being Fe_3O_4 or magnetic oxide of iron. A jet of pure oxygen is sent from an orifice in the centre of the nozzle that reacts with the iron at its ignition temperature. The velocity of the oxygen jet also removes the magnetic iron oxide from the cut face, or **kerf**.

As the ignition temperature is not as high as temperatures needed for fusion welding the use expensive acetylene gas is not needed. Propane, butane and other cheaper gases may be used for oxy-fuel gas cutting. The temperatures reached from the chemical exothermic reaction of oxygen with iron are sufficient to melt all metals and indeed most materials e.g. concrete. It is also the heating method used in the thermal boring/gouging tool known as a **Thermic Lance**, used in foundries for gouging inclusions in large castings.

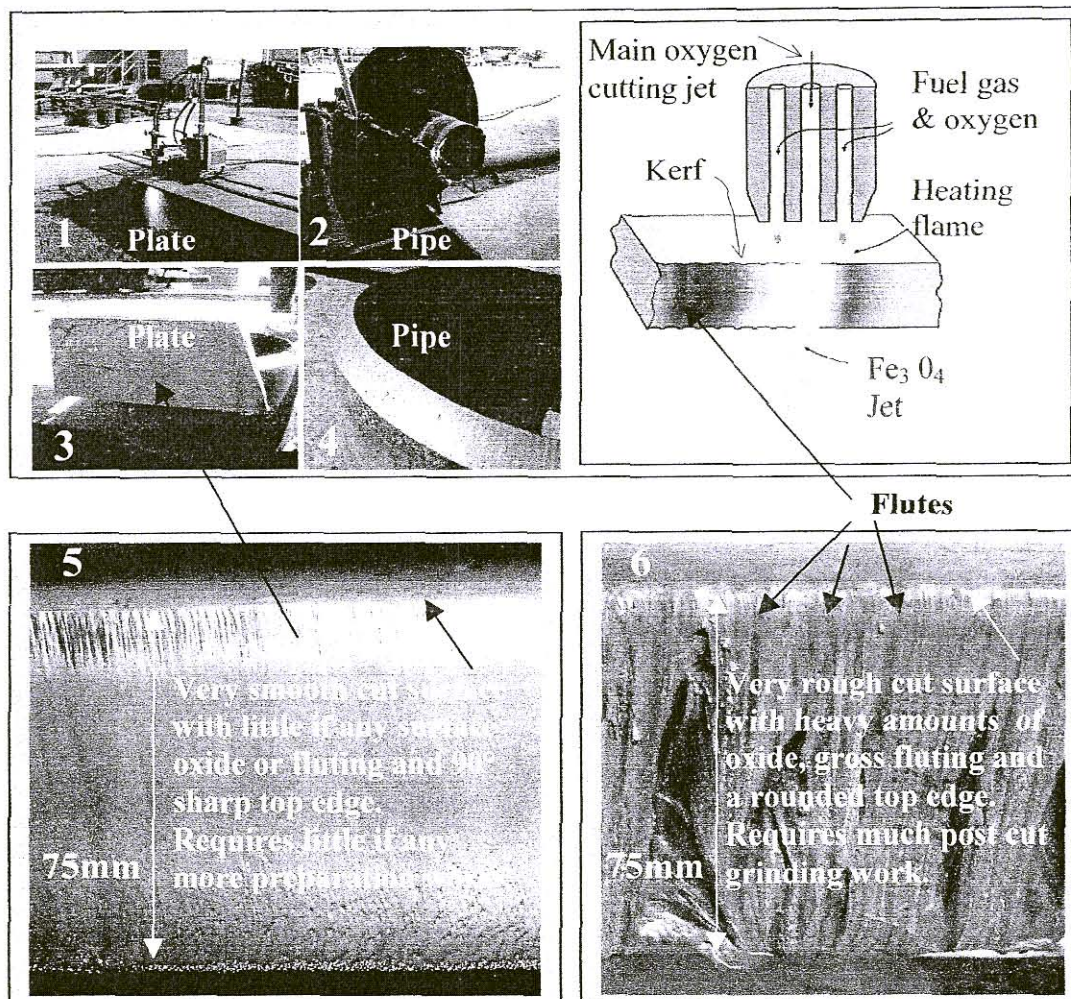
A restriction of oxy-fuel gas cutting is that it cannot be used successfully in its conventional form to cut metals with high melting point oxides (i.e. Stainless Steels). With the addition of an iron powder injection system, the iron-oxygen reaction can be produced ahead of the materials surface by the exothermic reaction of the heated iron powder within the oxygen jet. This enables all metals/alloys, to be cut with Oxy/Fuel gas cutting process, though if a **high quality** cuts are required then Plasma is much preferred.

The **thickness** of steels that may be cut using the Oxy-Fuel gas cutting method is dependant on the **nozzle size** and **oxygen pressure** available. The oxy-fuel gas cutting system may be simply mechanised and used to cut plates (Photograph 1) and preparations on pipe to be welded. (Photographs 2) It must be recognised that any steel with high hardenability may have hardened up to a depth of 3mm therefore dressing is normally required to remove this hardened region as well as removing any light oxide.

The main **inspection points** of conventional oxy fuel gas cutting will include: **Safety +**

- | | |
|---|---|
| 1) Cutting nozzle type, and size | 2) Nozzle distance from work |
| 3) Cutting oxygen pressure | 4) Speed of travel of the cutting head |
| 5) Angle of cut | 6) Fuel gas type and flame setting |
| 7) Pre-heat, if specified | 8) The condition of the kerf |

If all the above parameters are set correctly then the cut face or **kerf** should appear as in photographs 3 - 5 below. An example of incorrect parameters is shown in 6



A good oxy/fuel gas cut edge

A poor oxy/fuel gas cut edge

Arc Cutting (82) & Arc Gouging (87)

We can use the temperature attained by an electric arc in cutting processes to reach the temperatures required to melt the metal or alloy to be cut. There are 3 types of process that are generally used, the main differences being in the consumables and the gas used in producing the velocity required.

- 1) **Conventional cutting (82) gouging electrodes (87)**
- 2) **Oxy-Arc cutting (822) and gouging (872)**
- 3) **Arc-Air cutting (821) and gouging (871)**

Conventional cutting/gouging electrodes

In conventional arc gouging there is no requirement for any additional equipment other than that required for MMA/SMAW welding. The consumables consist of a light alloy central core wire, which is mainly to give rigidity, and a heavy flux coating, which provides elements that produce arc energy. The arc is struck in a conventional way to MMA welding, however the arc melts the base material, which is then pushed away by using a pushing action with the electrode. The process generates a great volume of welding fume and is not very effective, but is suitable for the occasional need to remove old welds, or gouge grooves in base metal.

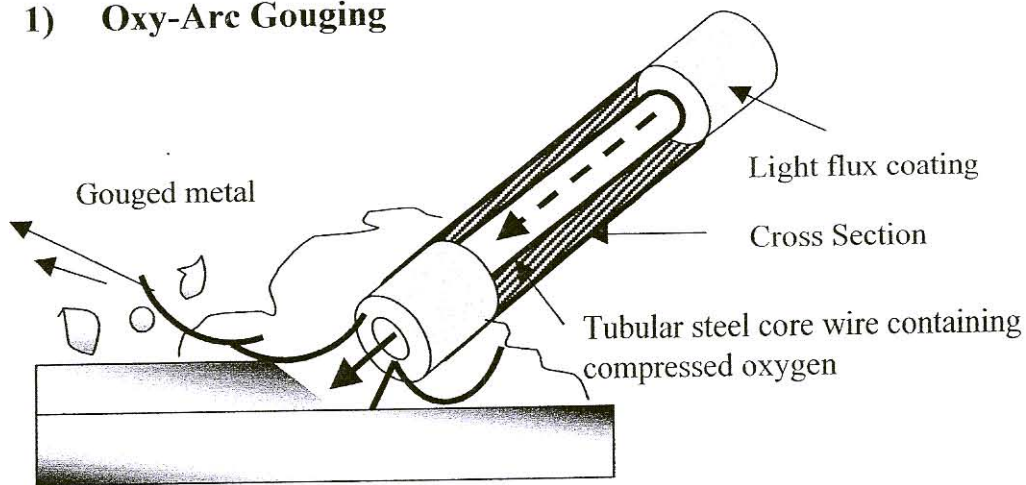
Oxy-Arc cutting/gouging

In oxy-arc cutting we require a special type of electrode holder. The consumables are tubular in section and are coated with a very light flux coating. The electrode is located in the special electrode holder to which is attached a power cable and gas hose. The power cable is attached to the power source and the gas hose is attached to a source of compressed oxygen. The arc is struck and the compressed oxygen may be activated at the torch head. The heat of the electric arc will melt the base metal or alloy and the velocity to remove it is provided by the compressed oxygen. When cutting ferritic alloys, a similar effect can be produced to the exothermic reaction found when using conventional oxy-fuel gas cutting. This process is generally used for decommissioning/scraping plant as the cut surface is generally not consistent.

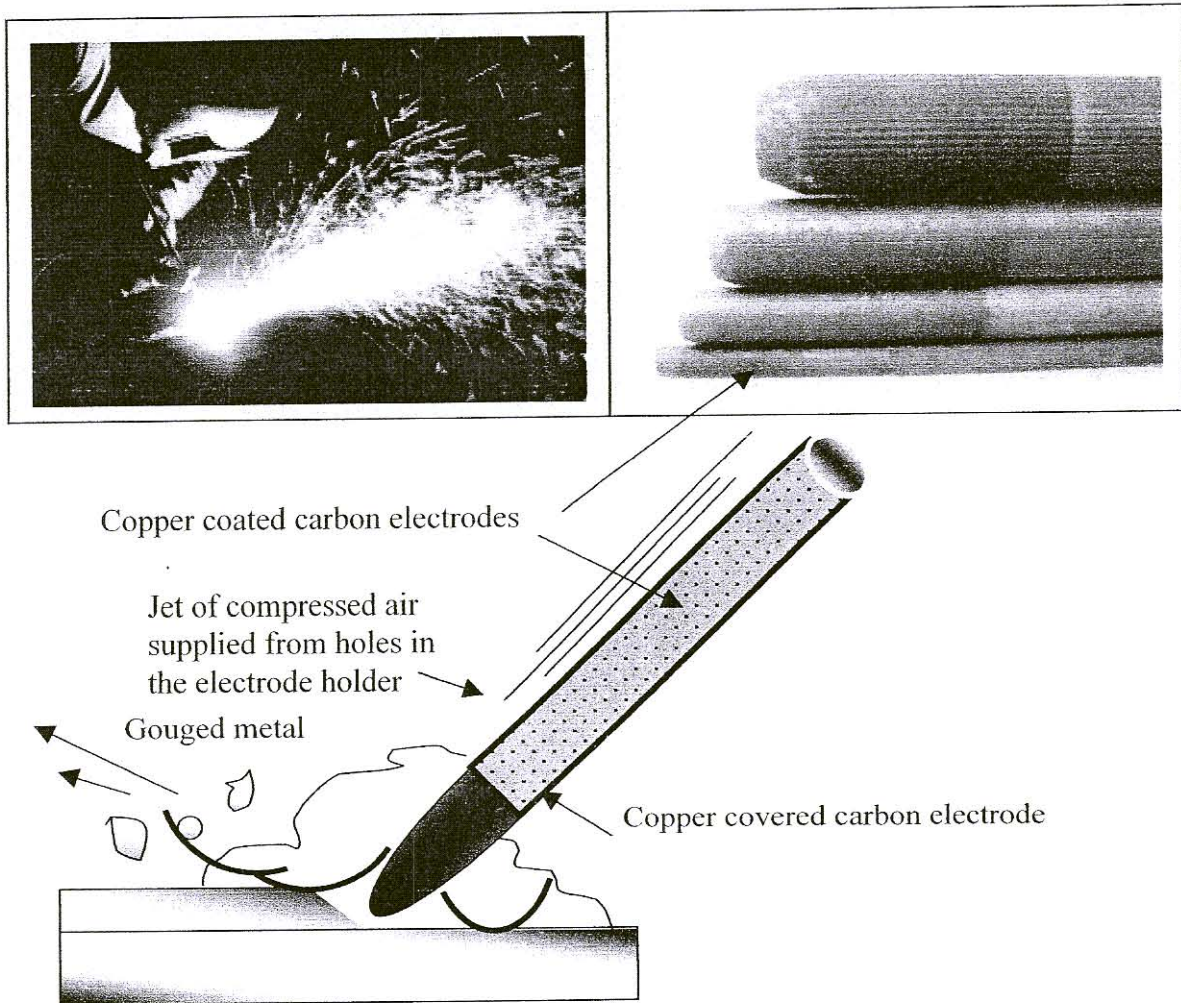
Arc-Air cutting/gouging

Arc-air cutting is the **most commonly used** method of arc cutting/gouging and is used extensively for gouging old welds and removing materials. The consumable is a copper coated carbon electrode with the gas being compressed air. The process is basically “**melt and blow**” in that there is no exothermic reaction producing extra heat within the cut zone. The main disadvantages include the high level of high-pitched noise produced and the volume of fumes generated. The cut face will require dressing due to potential carbon pick up and the rapid heating/ cooling cycle involved. A major safety inspection point in the use of all arc processes is that correct ear protection is in use and also that an efficient fully isolated breathing supply system is also being used.

1) Oxy-Arc Gouging



2) Arc-Air Gouging

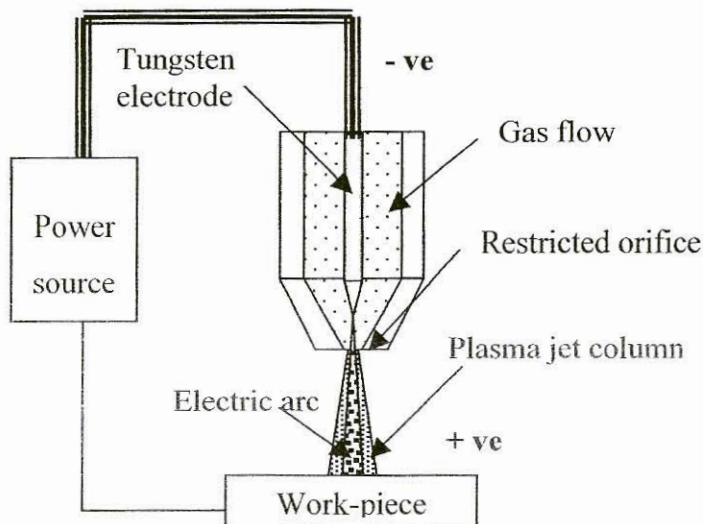


Plasma Cutting (83) and Gouging (88)

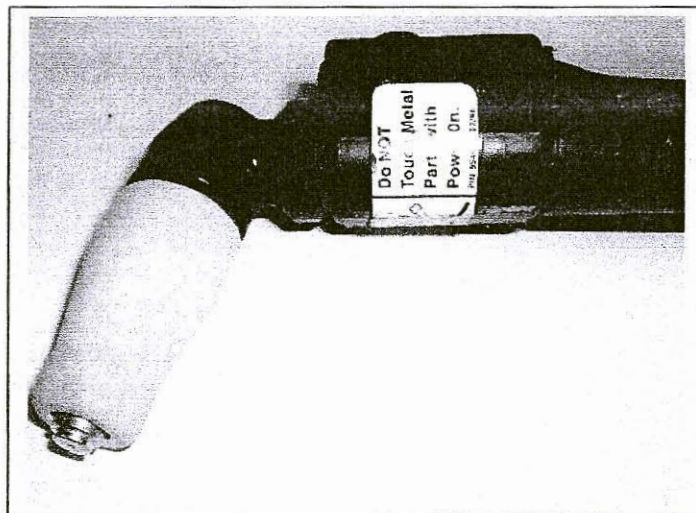
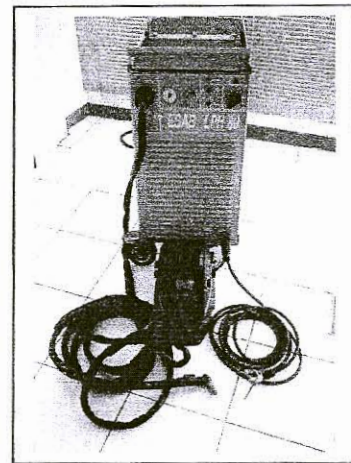
Plasma cutting utilises the temperatures reached from the production of the plasmas from certain types of gases. Nitrogen gas plasma can reach a temperature of over 20,000°C but temperature of air plasma is much lower. Air however is freely available and therefore cheaper and can be compressed by a compressor in the equipment, but is restricted in the depth of cut attainable. The velocity for plasma cutting is produced by the expansion of the plasma in the torch chamber, which is then forced through a constricting orifice at the torch head producing the velocity required. There are essentially 2 main categories of the plasma cutting process:

- 1) **Transferred arc** (Used for cutting conductive materials)
- 2) **Non-transferred arc** (Used for cutting non-conductive materials, such as cloth)

Transferred Plasma Arc Cutting



Air Plasma Cutting Equipment



Air Plasma Cutting Torch

Laser Cutting (84)

The laser jet can also be adapted for cutting materials, with the adaptation of a high velocity gas jet to remove the vaporised metal from the cut area. Laser cutting is a very expensive operation as the laser and the material handling equipment is expensive but it gives an extremely accurate cut. It has recently become more widely used in applications demanding this high level of accuracy, mainly through the advent of Nd-YAG laser, which due to the frequency of its laser light has ability to be directed along fibre optics. Thus the development of robotics systems carrying laser cutting heads producing continuous levels of extremely high accuracy cutting in fully automated systems are now not uncommon in certain areas of the fabrication industry.

High Speed Water Jet Cutting

Although technically this method of cutting does not belong within a thermal cutting section, it is becoming increasingly used in the Petrochemical industry and thus requires some explanation. It utilises water borne particles as a high speed abrasive and is used predominantly in the Petrochemical Industry as a means of cutting old steel pipeline and structures within **high fire risk** areas. A main advantage is the absence of any HAZ.

WIS 5 Section 20 Exercises:

- 1) List 7 further inspection points of the oxy-fuel gas cutting process?

1. Cutting Nozzle Type and Size

2. _____

3. _____

4. _____

5. _____

6. _____

7. _____

8. _____

- 2) From information in your notes and the course lecture insert an advantage and disadvantage of the following cutting processes:

Cutting Process	Advantage	Limitation
Basic Oxy Fuel Gas Cutting/Gouging		
Conventional Arc Cutting		
Oxy Arc Cutting/Gouging		
Arc Air Cutting/Gouging		
Plasma cutting		
Laser cutting Nd YAG		
Laser cutting CO ₂		
High speed water jet cutting		

WIS 5 Welding Inspection

Section 21

Welding Safety

Welding Safety:

As a respected officer it is a **duty** of any welding inspector to ensure that safe working practices are strictly followed at all times.

Safety in welding can be divided into specific areas some of which are as follows:

- 1) *Welding/cutting process safety*
- 2) *Electrical safety*
- 3) *Welding fumes & gases (Use & storage of gases)*
- 4) *Safe use of lifting equipment*
- 5) *Safe use of hand tools and grinding machines*
- 6) *General welding safety awareness*

1) Welding/cutting process safety:

Consideration should be given to safety when using gas or arc cutting systems by:

- a) Removing any combustible materials from the area.
- b) Checking all containers to be cut or welded are fume free
(All valid **Permits to work** are in place etc.)
- c) Providing ventilation and extraction where required
- d) Ensuring good gas safety is being practised
- e) Keeping oil and grease away from oxygen
- f) Appropriate PPE is worn at all times

2) Electrical Safety:

Safe working with electrical power is essential; ensure that insulation is used where required and that cables and connections are in good condition, being especially vigilant in wet or damp conditions. Low voltage supply (**110 v**) must be used where appropriate for all power tools etc. All electrical equipment must be regularly tested and identified as such accordingly.

3) Gases & Fume Safety:

The danger of exposure to dangerous fumes and gases in welding cannot be over emphasised. Exposure to metallic fumes and/or gases may come from electrodes, plating, base metals and any gases that are used in or produced during the welding cycle.

Dangerous gases that may be produced during the welding process include **ozone**, **nitrous oxides**, and **phosgene** (caused by the breakdown of **Trichloroethylene** based degreasing agents in arc light); all of which are **extremely poisonous** and will result in **death when over-exposure occurs**.

Other gases used in welding can also cause problems by displacing air or reducing the oxygen content.

Most gases are stored under high pressure, and therefore the greatest care should be exercised in the storage and use of such gases. All gases should be treated with respect and are considered a major hazard area in welding safety.

Cadmium, **chromium**, and other metallic fumes are extremely toxic and again may result in **death if over-exposure** occurs. Be aware of the effects of a coating fume and always use correct extraction or breathing systems, which are essential items in safe welding practice.

If in doubt stop the work!

Until a health and safety officer takes full responsibility.

4) Lifting Equipment:

It is essential that correct lifting practices are used for slinging and that strops of the correct load rating are used for lifts. All lifting equipment is subject to regular inspection according to national regulations in the country concerned. In the UK this is governed by the HSE under the LOLER requirements, which are mandatory for all operations within the UK. Cutting corners is an extremely dangerous practice when lifting and often leads to fatalities. (Never stand beneath a load)

5) Hand tools and grinding machines:

Hand tools should always be in a safe and serviceable condition (grinding machines should have wheels changed by an approved person) and should always be used in a safe and correct manner. Use cutting discs for cutting and grinding discs for grinding only.

6) General:

Accidents do not just happen but are usually attributable to someone's **neglect** or **ignorance** of a **hazard**. Be aware of the hazards in any welding job and **always minimise** the **risk** and **always** refer to your **safety advisor** if **any doubt exists**.

Special Terms Related to Welding Safety

Duty cycle

A **Duty Cycle** is the amount of current that can be safely carried by a conductor in a period of time. The time base is normally 10 minutes and a 60% duty cycle means that the conductor can safely carry this current for 6 minutes in 10 and then must rest and cool for 4 minutes. At a 100% duty cycle equipment can carry the current continuously. Generally **60% & 100%** duty cycles are given for welding equipments.

Example: 350amps at 60% duty cycle and 300amps 100% duty cycle.

This should not be confused with the term **Operating Factor**, often wrongly used for **Duty Cycle** as both are given as a **percentage %**. **Operating Factors** are multiplied by process deposition rates in economic calculations to calculate the full costs of welding, including process down (non arc on) time. Some **typical** process **Operating Factors** are:

MMA = **30%**

MIG/MAG Semi automatic Manual operation = **60%** (Hence confusion with **duty cycle**)

MIG/MAG Semi Automatic Mechanised/Robotics (Fully automated) operation = **90%**

Occupational, and Maximum Exposure Limit (OEL and MEL)

Operational, and Maximum Exposure Limits **OEL & MEL** may be defined as a safe, and maximum working limit of exposure to various fume, gases or compounds during certain time limits, as calculated by the Health and Safety Executive or **HSE** in the UK.

Examples of levels of some fume and gases that workers may be exposed too are taken from **Guidance Note EH/40 2002** and given in the table below:

Fume or gas	Exposure Limit	Effect on Health
Cadmium	0.025Mg/m ³	Extremely toxic
General Welding Fume	5Mg/m ³	Low toxicity
Iron	5Mg/m ³	Low toxicity
Aluminium	5Mg/m ³	Low toxicity
Ozone	0.20 PPM	Extremely toxic
Phosgene	0.02 PPM	Extremely toxic
Argon	No OEL Value O ₂ air content to be controlled	Very low toxicity

*** Note: Any MEL/OEL values given in Guidance Note EH/40 may change annually**

The toxicity of these examples can be gauged by the value of exposure limit. Any of the above examples may be present in welding under certain conditions, which will be expanded upon by your course lecturer at a relevant point.

WIS 5 Section 21 Exercises:

Complete the table below by inserting any safety issues that will need to be considered?

Material	Process	Other Information	Issues to be considered
Stainless Steel	MAG	Vessel contained explosive & toxic compounds	
Stainless Steel	Silver braze	Cd braze alloy	
Steel	Gas Welding	Galvanized	
Steel	MMA	Cadmium plated	
Steel	TIG	Degreased with Trichloroethylene, but still damp	
Steel	Arc Air Gouging	Confined space	
Steel	Overhead Lift	500 tonnes	
Steel	MMA	Site work Wet conditions	
Stainless Steel	TIG	Confined space	
Steel	Oxy – Fuel cutting	In an area containing combustibles	

Spot the Safety Hazards!!



WIS 5 Welding Inspection

Section 22

The Weldability of Steels

The Weldability of Steels:

In general, the term **weldability** of materials can be defined as:

“The ability of a material to be welded by most of the common welding processes, and retain the properties for which it has been designed”

The weldability of steels can involve many factors depending on the type of steel, the process and the mechanical properties required.

Welding engineers concerned with welding only C/Mn structural steels may often define weldability as **carbon equivalent**, however this is a very narrow application of this term.

Poor weldability generally results in the occurrence of some type of cracking problem, though most steels have a degree of weldability.

When considering any type of weld cracking mechanism there must be three essential elements present prior to its occurrence:

- 1) **Stress.**
- 2) **Restraint.**
- 3) **Susceptible microstructure.**

1. Residual stress is always present in weldments, through local expansion & contraction.
2. Restraint may be a local restriction, or through plates being welded to others.
3. The microstructure is often made susceptible to cracking by the process of welding.

The types of cracking mechanism prevalent in steels in which the **CSWIP 3.1 Welding Inspector** should have some knowledge are:

1. **Hydrogen induced HAZ cracking. (C/Mn steels)**
2. **Hydrogen induced weld metal cracking. (HSLA steels)**
3. **Solidification cracking. (All steels)**
4. **Lamellar tearing. (All steels)**
5. **Inter-crystalline corrosion. (Stainless steels)**

Definitions:

For this section it is essential to have a basic understanding of the following terms:

Solubility:	To be able to dissolve one substance in another, like sugar in tea.
Maximum Solubility:	The maximum % of a substance that can be dissolved in another.
Steel:	An alloy of the iron with the non-metal carbon . (0.01 – 1.4% C)
Plain Carbon Steels:	Steels that contain only iron & carbon as main alloying elements. Traces of Mn, Si, Al, P & S may be also present from refining.
Low Carbon Steel:	Plain carbon steels containing between 0.01 – 0.3% C
Medium Carbon Steel:	Plain carbon steels containing between 0.3 – 0.6% C
High Carbon Steels:	Plain carbon steels containing between 0.6 – 1.4 % C
Low Alloy Steels:	Steel containing iron and carbon, and other alloying elements i.e. Mn, Cr, Ni, Mo < 7% Total
High Alloy Steels:	Steel containing iron and carbon, and other alloying elements i.e. Mn, Cr, Ni, Mo > 7% Total
Ferrum:	The <i>Latin</i> term for Iron from which comes its chemical symbol Fe
Ferrite:	A low temperature structure of iron & dissolved carbon, the maximum solubility of carbon occurring in this structure is 0.02 %
Austenite:	A high temperature structure of iron & dissolved carbon, the maximum solubility of carbon occurring in this structure is 2.06%
Martensite:	A hard structure produced in some steels by the rapid cooling from high temperature austenite, generally occurs at temperatures <300°C
Diffusion:	The movement of solute atoms, or molecules through a crystalline structure. This can generally be accelerated with increasing levels of heat energy in the material.

Effect of alloying elements:

Elements may be added to steels to produce the properties required to make it useful for an application. Most elements can have many effects on the properties of steels.

Aluminium:	Alloyed to steels mainly as a grain refiner, and is also used as a de-oxidising agent in triple de-oxidised steel and welding consumables.
Carbon:	A prime and essential element in steel alloys. An increase in Carbon content will increase hardness and strength, but reduces the ductility.
Chromium:	Alloyed in additions $> 12\%$ to produce stainless steels, but is often used in low alloy steels $< 5\%$ to increase hardness strength and greatly increase the resistance to oxidation at higher temperatures. Chromium stabilises carbide formation, but promotes grain growth if added in isolation. It is thus often alloyed together with Ni or Mo
Manganese:	Alloyed to structural steels $< 1.6\%$ to increase the toughness and strength. It is also used to control solidification cracking in ferritic steels and alloyed up to 14% in wear/impact resistant Hadfield steel.
Molybdenum:	Alloyed to low alloy steels to control the effects of creep. It is also used as a stabilising element in stainless steels, and will limit the effects of grain growth. Alloyed in Cr/Ni/Mo low alloy steels to control an effect called temper embrittlement.
Nickel:	Nickel is alloyed $> 9\%$ steel producing austenitic stainless steel. It is also be added $< 9\%$ in the low temperature nickel steels. It promotes graphitisation, but is good grain refiner, and is often used to offset some effects of Chromium. Nickel is very expensive, but improves the strength, toughness, ductility and corrosion resistance of steels.
Niobium:	Carbide former used to stabilise stainless, also in HSLA $< .05\%$
Silicon:	Is alloyed in small amounts $< 0.8\%$ as a de-oxidant in ferritic steels. It is alloyed to valve and spring steels, and can also increase fluidity.
Titanium:	Used mainly to stabilise stainless steel, and $< .05\%$ in HSLA steels.
Tungsten:	Mainly alloyed to high alloy High Speed Tool steels. This increases the high temperature hardness required of such steels, due to the tempering effect of frictional heat on other steels during cutting.
Vanadium:	Used as a de-oxidant, or as a binary alloy as in HSLA steels $< .05\%$

It should be remembered that most alloying additions increases the ability of a steel to harden by the thermal hardening process. This property is termed "**hardenability**"

Crack type:

Hydrogen cracking (H₂ cold cracking)

Location:

a. HAZ. Longitudinal

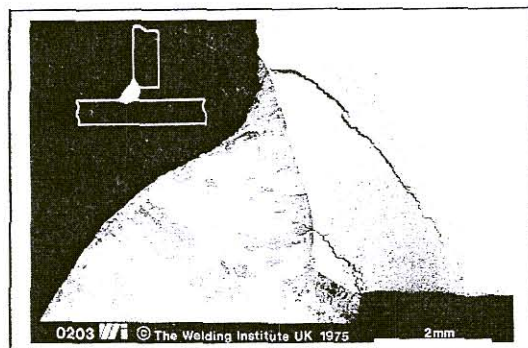
Steel types:

b. Weld metal. Transverse or longitudinal

a. All **hardenable steels** i.e. Low alloy steels. HSLA steels. QT Steels. Med – High C steels.

Susceptible microstructure:

Martensite.



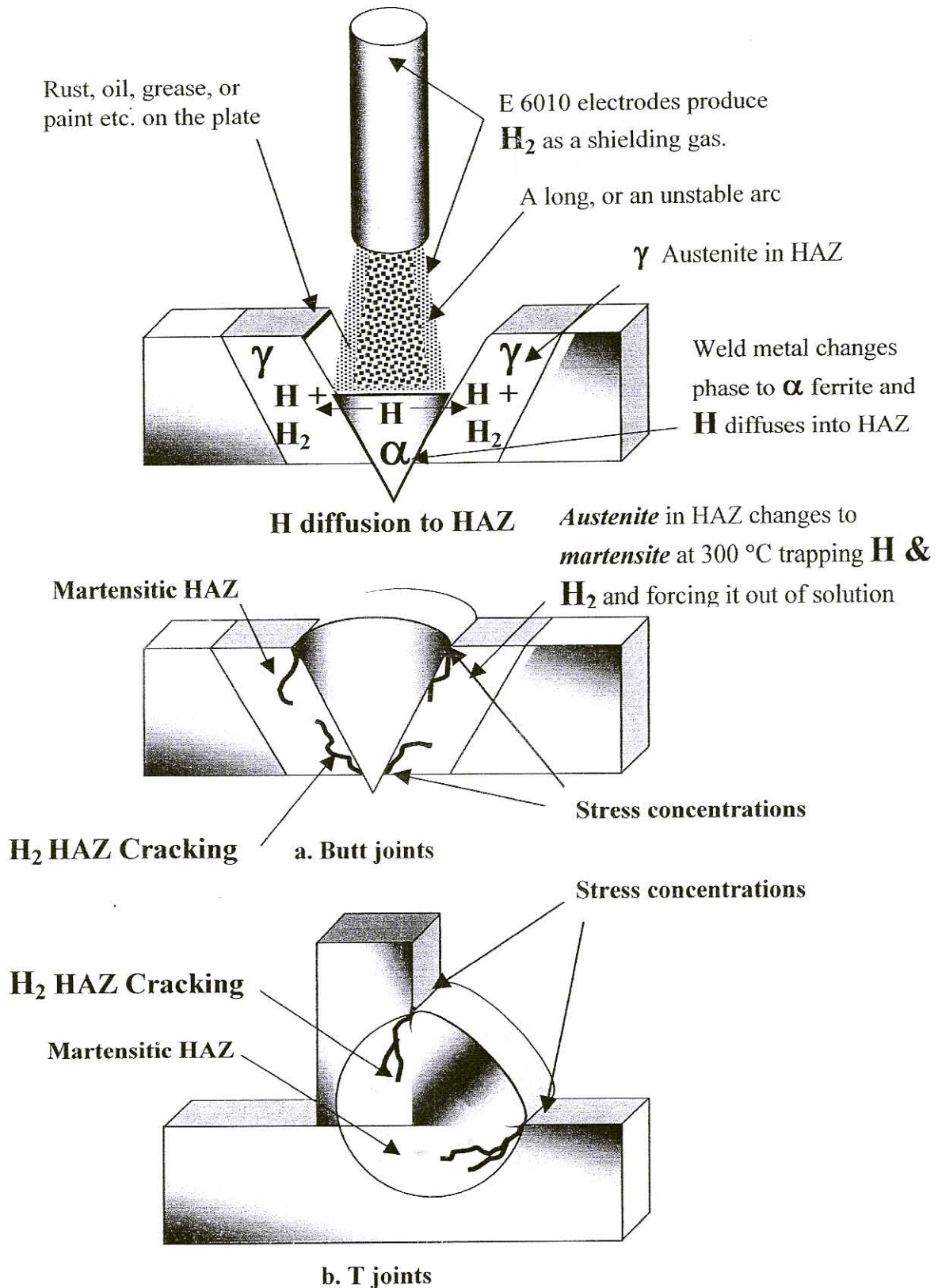
Causes:

H₂ cracking is a *cold* cracking mechanism *generally* occurring *below 300 °C* and may be found in the HAZ or weld metal depending on the type of steel being welded. H₂ may be absorbed into the welding arc from many sources including; moisture on plates or in the air, paint or oil on the plates, or a long or unstable arc etc. An E6010 cellulosic electrode produces mainly H₂ as its shielding gas. H₂ will easily dissolve into solution in molten weld metal and remain in solution upon solidification into either delta ferrite or austenite. As the weld cools below the LCT the weld metal transforms into alpha ferrite/pearlite that has far less solubility for H₂ and at this point the H₂ will tend to move into the HAZ where austenitic is still retained. The process is termed *diffusion*, which occurs more rapidly at elevated temperature. If the HAZ is of *low hardenability* it will itself transform into ferrite/pearlite and H₂ will remain in solution, eventually diffusing out of the weldment. If the HAZ has *higher hardenability* then the transformation of the HAZ will be from austenite to martensite, which as a supersaturated solution of iron and carbon offers *no solubility* for H₂. This will result in expulsion of H₂ from solution and a high level of internal stress occurring in this brittle microstructure that also offers no ductility. Cracks may occur from areas of high stress concentration, such as from the toes of welds and generally move through the hardened *HAZ*, though in some cases the *weld metal*.

The four critical factors and values, where hydrogen cracks are likely to occur, are considered to be:

- Hydrogen content: > 15 ml/100 gm of deposited weld metal
- Hardness: > 350 HV
- Stresses: > 0.5 of the yield stress
- Temperature: < 300°C

Hydrogen may be absorbed into the arc zone and liquid weld metal from:



Prevention of hydrogen HAZ cracking:

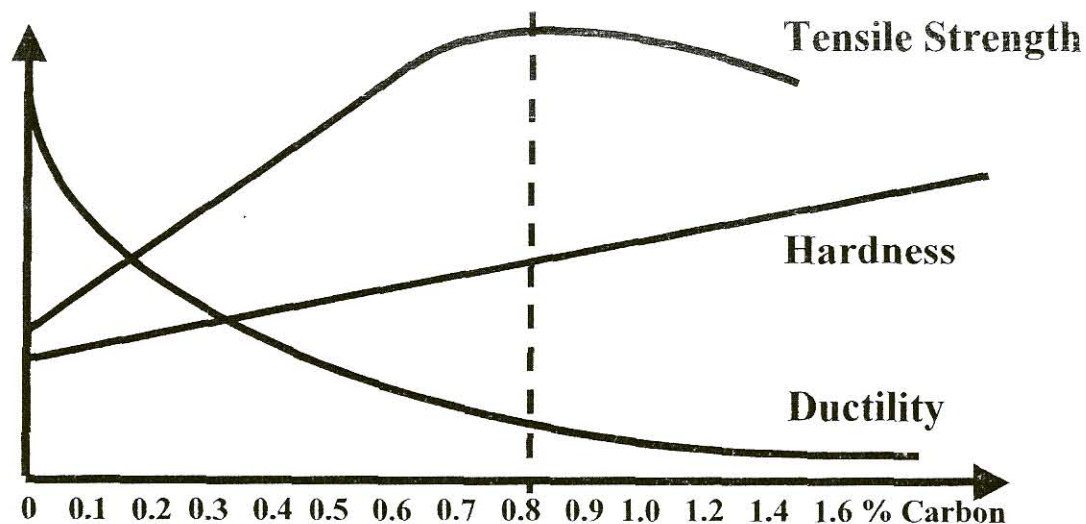
To control hydrogen cracking in the HAZ it may be necessary to pre-heat the weldment. Pre-heating retards the rate of cooling and suppresses the formation of martensite and other hard structures formed upon rapid cooling. It will also promote diffusion of trapped H_2 back to the atmosphere.

Considerations during calculation of pre-heat requirements are:

- a. **Hardenability** of the joint (i.e. C_{eq})
- b. **Thickness** of metal and joint type
- c. **Arc energy** input.
- d. **Hydrogen** scale, or achievable limit

Hydrogen Induced Weld Metal Cracking:

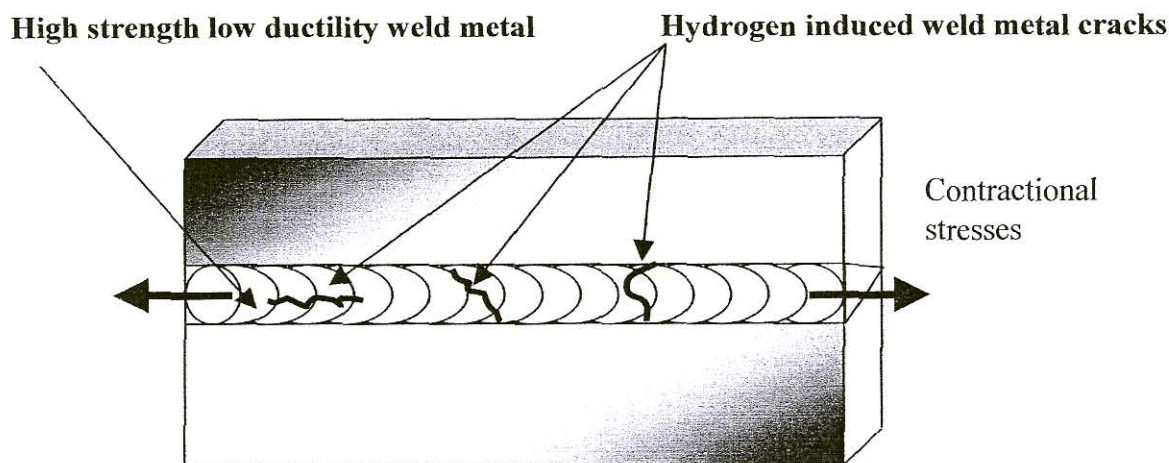
H_2 weld metal cracks may occur when welding **HSLA** (High strength low alloy) steels. These steels are micro-alloyed with titanium, vanadium and/or niobium. (Typically 0.05%) To cheaply match weld strength to plate strength the choice weld metal with increased carbon content is used as increased carbon content increases tensile strength. (Up to 0.83% C) A graph showing the effect of carbon on the properties of plain carbon steels is given below. This action will also result in a hardenable steel weld deposit where austenite in the weld will transform directly into martensite causing the same conditions as found in the HAZ previously, and where cracking may now occur within the weld metal. Both HAZ and weld metal H_2 cracks are considered as cold cracks ($< 300^\circ\text{C}$) and on occasions are referred to as " *H_2 induced or delayed cracking*". If H_2 cracks are suspected final inspection may be *delayed up to 72 hours*, depending upon application code/standard requirements as cracks may appear within this time.



As indicated above, additions of carbon (up to 0.83%C or Eutectoid composition) will increase the tensile strength of plain carbon steel. This serves the purpose of cheaply matching the weld metal strength to the base metal but will also give the weld metal much higher *hardenability*.

These conditions may now result in H₂ cracking occurring in the weld metal, as the weld will now transform directly from *austenite* – *martensite* trapping the H₂ in weld metal and inhibiting its diffusion to the HAZ.

It can also be seen from the graph that higher carbon steels have much reduced levels of ductility. Cracks tend to be transverse as the main residual stresses are generally in the longitudinal direction, though they may occasionally be longitudinal, or even at 45° to the weld metal.



Prevention of cracking for these steels is as per H₂ HAZ cracking where preheating of the weld area permits a degree of trapped H₂ time at temperature to *diffuse* from the weld and HAZ area back to the atmosphere, and as importantly retards the formation of the hard martensitic structure.

Summary of prevention methods for H₂ cracking in Low Alloy and Micro Alloy Steels:

- Use a low hydrogen process and/or hydrogen controlled consumables.
- Maximise arc energy (taking HAZ and weld toughness into consideration).
- Use correctly treated H₂ controlled consumables
- Minimise restraint.
- Ensure plate is dry and free from rust, oil, paint or other coatings.
- Use a constant and correct arc length.
- Ensure pre-heat is applied and maintained before any arc is struck.
- Control inter-pass temperature
- Ensure welding is carried out under controlled environmental conditions

The selection of an austenitic stainless steel weld metal will also control the effects of H₂ cracking but may also form an unacceptable corrosive condition to exist.

It should also be noted that it is possible for *monatomic hydrogen atoms* (H) to be trapped within the martensitic structure that has reached temperatures where *diatomic hydrogen* (H₂) should now exist. This will also result in atomic forces acting within the structure and should be considered as a contributory factor in this cracking mechanism, in *weld or HAZ*.

Crack type:

Solidification cracking (Hot cracking)

Location:

Weld centre. (Longitudinal)

Steel types:

All

Susceptible microstructure:

Columnar grains.

(In the direction of solidification)



Causes:

Solidification cracking is a **hot cracking** mechanism that occurs during solidification of welds in steels having high sulphur content or contaminated with sulphur. A further potential cause is the weld depth/width ratio, which in normal welding situations refers to deep narrow welds (cladding applications may produce shallow wide welds, as these are also prone to this problem). Therefore if we have a combination of deep narrow welds with a high incidence of sulphur we are greatly increasing the likelihood of hot cracking. As with all cracking mechanisms stress plays a major role in susceptibility. During welding sulphur in or on the plate may be re-melted and will chemically join with the iron to form iron sulphides. Iron sulphides are low melting point impurities that will naturally seek the last point of solidification in the weld, which is on the weld centreline. It is here that still being above their melting point and hence liquid that they form liquid films around the hot solidifying grains that are themselves under great stress due to the actions of contractional forces. The bonding between grains may now be insufficient to maintain cohesion required in accommodating the opposing contractional stresses within weld and HAZ, and a crack will result along the length of the weld on its centreline.

Prevention of solidification cracking in ferritic steels: To prevent the occurrence of solidification cracking in ferritic steels that contain high levels of sulphur (these steels are said to suffer from **Hot Shortness**), manganese is added to the weld via the consumable.

Sulphur related

Scrutiny of Mill sheets is essential to assess the materials Sulphur content. A typical maximum level allowed in a low carbon steel specification is 0.05%. Even this seemingly low figure may be excessive for certain high stress/higher carbon applications, or if the depth/width ratio is excessive.

A further potential source of Sulphur is paint, oil and grease and is why temperature crayons always carry the statement “**Sulphur Free**” and is a prime reason for **thorough cleaning**. This becomes of **critical importance** when welding **austenitic stainless steels**.

If limited material availability requires the welding high sulphur steels then consumables with relatively high manganese content are specified. An example of steel with very high sulphur levels would be **Free Cutting/Machining** steel. Some of these steels could be considered as un-weldable in normal circumstances as sulphur levels are very high.

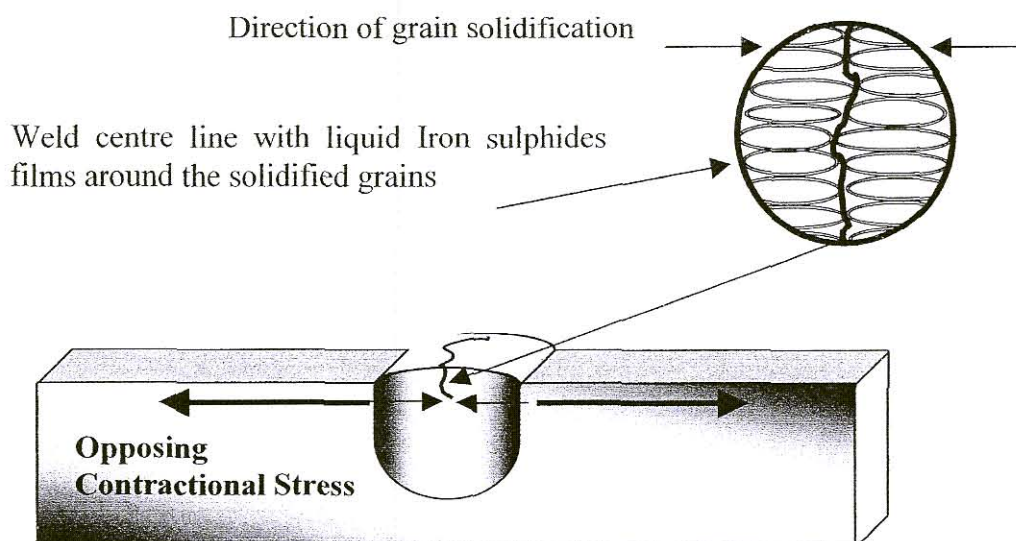
Manganese has the effect of forming preferential manganese sulphides with the sulphur. Mn/S are spherical and solidify at a higher temperature than iron sulphides and therefore are more dispersed throughout the weld. Cohesion between the grains is thus maintained and the crack will not occur.

Careful consideration must be given to the Mn/S ratio, which at 0.12% C should be in the region of about 40:1. Increased carbon content can rapidly increase the required ratio exponentially; thus carbon must be reduced as low as possible, with low plate dilution and low carbon, high manganese filler wires.

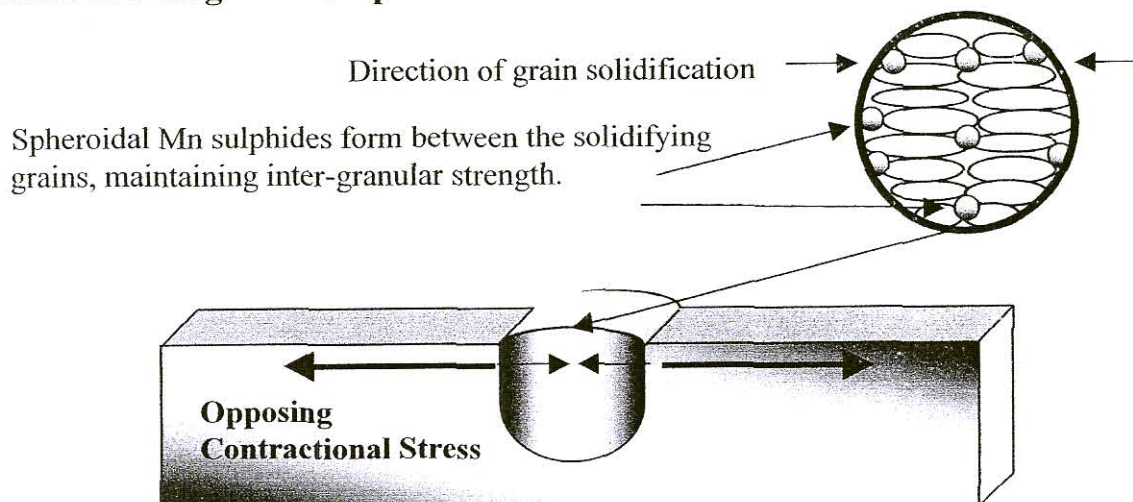
A summary of prevention methods:

- | | |
|---|-----------------------------------|
| a. Use low dilution processes | b. Use high manganese consumables |
| c. Maintain a low carbon content | d. Minimise restraint/stress |
| e. Specify low sulphur content of plate | f. Remove laminations |
| g. Thorough cleaning of preparation | h. Minimise dilution |

Solidification cracking (Sulphur related)



Effect of Manganese Sulphides formation



Depth/width ratio related

The shape of the weld will also contribute to the possibility of cracking. This may be totally independent from the sulphur aspect but is usually in combination. Processes such as FCAW SAW and MAG (using spray/pulsed transfer) may readily provide these deep/narrow susceptible welds. However it is not the weld volume that is the prime factor but the weld shape as referred to previously. Therefore root runs and tack welds may readily provide the susceptible profile. As root runs are also areas of high dilution (therefore greater sulphur pick up) and more likely to be highly stressed these must always be inspected with solidification cracking in mind.

Solidification cracking in Austenitic Stainless steels

Austenitic stainless steel is particularly prone to solidification cracking.

This is primarily caused through:

A comparatively large grain size, that gives rise to a reduction of grain boundary area. A high coefficient of thermal expansion, this produces high resultant stresses to occur. An atomic structure that is very intolerant of contaminants, such as sulphur, phosphorous and additional elements such as boron. The cause and avoidance may be regarded as the same as that of plain carbon steels, but with extra emphasis on **thorough cleaning requirements** prior to welding. The welding procedure will have been written to control the balance of austenite and ferrite in the weld metal. This balance will directly affect the structures tolerance of contaminants and the resultant grain boundary area, and is why the filler material specified often does not appear to match the parent material. Careful monitoring of parameters is required to **control dilution** to ensure this balance is maintained.

Crack type:

Location:

Steel types:

Susceptible microstructure:

Lamellar tearing.

Parent material

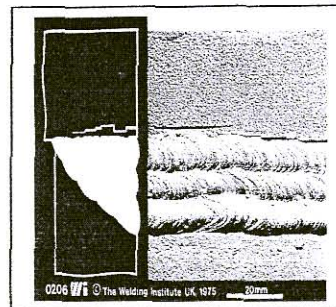
All steels

Low through thickness ductility

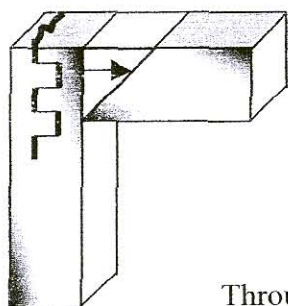
Causes:

During welding high levels of contraction stress may be passed in the through thickness direction of one of the plates within the joint. This **short transverse direction** generally lacks in **ductility** particularly in cold rolled plates. As ductility is the property required in the steel to accommodate this plastic strain caused by contraction stresses a **stepped like crack** may initiate in the affected plate just below the HAZ in a horizontal plane.

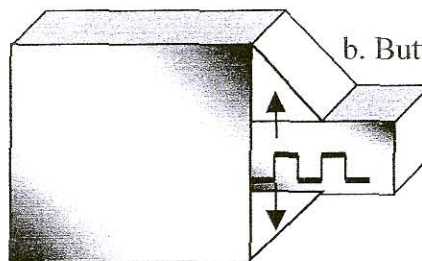
Micro inclusions of impurities such as sulphides and silicates that may occur during steel manufacture are also a contributory cause, which when subjected to short transverse stresses may lead to lamellar tearing



Lamellar tearing. (Ferritic steels)

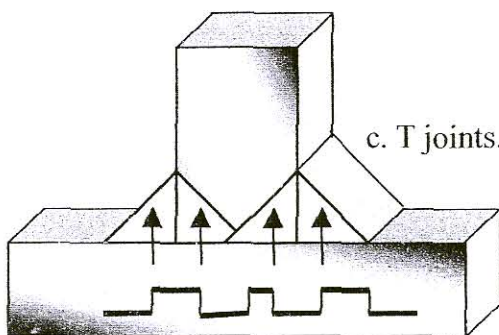


a. Corner joints.

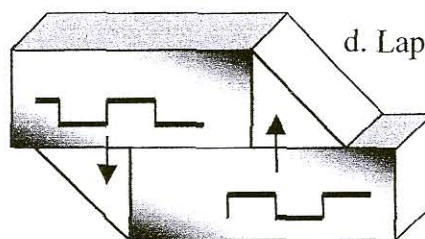


b. Butt joints.

Through thickness contraction stress = →



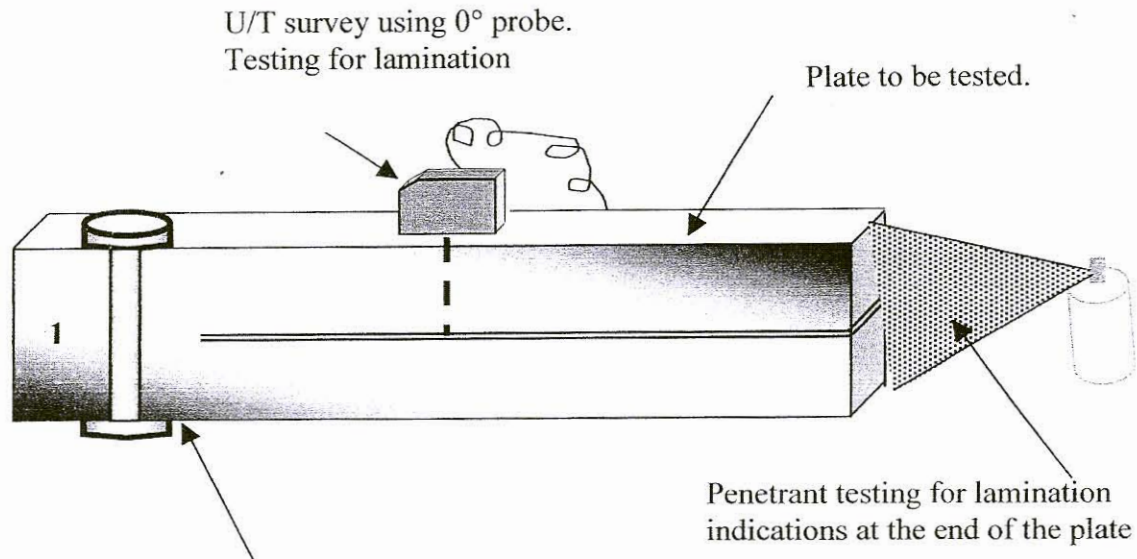
c. T joints.



d. Lap joints.

To assess the risk of a materials susceptibility to lamellar tearing through thickness tensile tests are normally carried out.

Testing a steel for susceptibility to lamellar tearing



Machined *transverse* tensile specimen with *Friction* welded ends.
Testing for a minimum value of % *reduction in CSA*

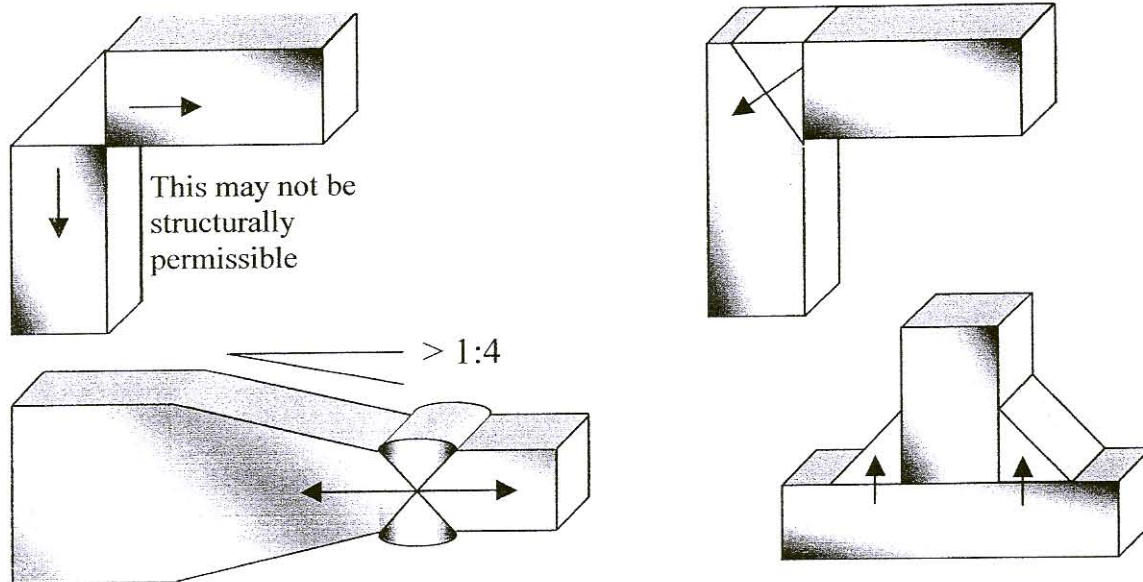
A test can be made on the level of through thickness ductility, which to avoid lamellar tearing should show a certain minimum level. The results are normally given in % Reduction in Cross Sectional Area (or CSA). The **critical value** is generally considered as **20%**. The lower the value below this threshold, then the higher is considered the risk of lamellar tearing occurring in joints with high through thickness contractional stresses.

Prevention of lamellar tearing:

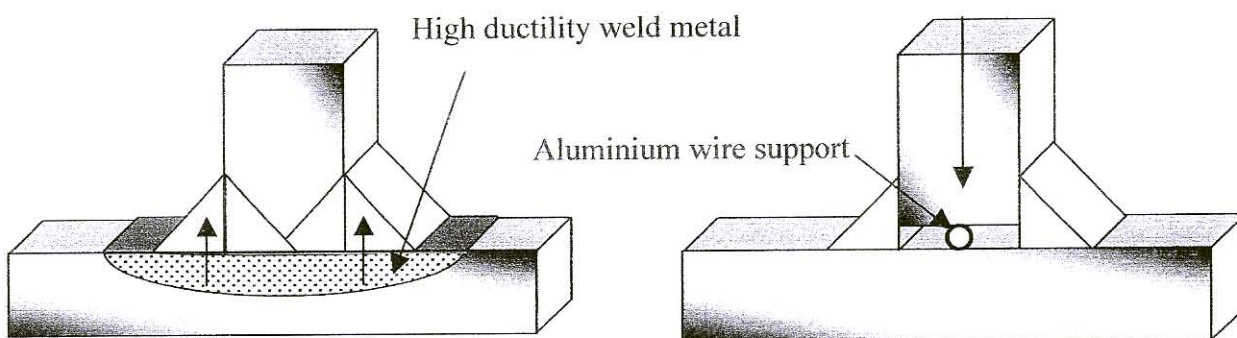
To reduce the risk of lamellar tearing the following steps may be taken:

- Check the chemical analysis (**Below 0.05% S or P**)
- Check laminations with UT (PT on plate edges)
- Check the short transverse ductility value (**> 20% Reduction in CSA**)
- Use buttering layer of high ductility weld metal deposited beneath the member to be welded, enabling contractional stresses to be absorbed as plastic strain.
- Leave a contraction gap between members enabling any contractional movement.
- Re-design of the weld.
- Re-design of the joint.
- The use of pre formed T pieces. (Mainly in **critical** applications)

Methods used to control the occurrence of lamellar tearing:

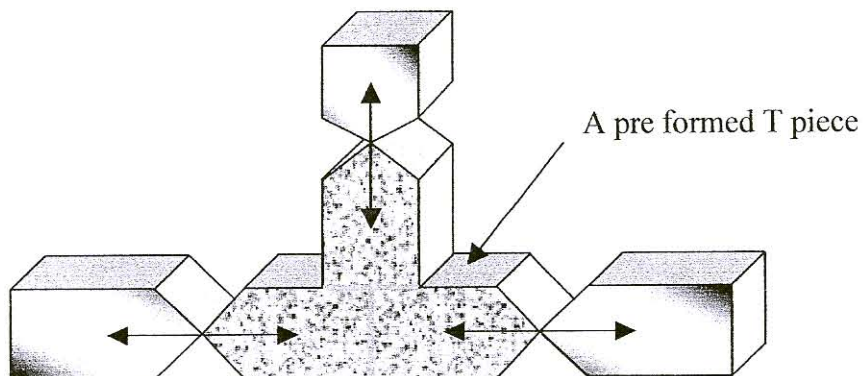


1) Change of joint and or weld design (Where possible, practical and permissible)



2) Use ductile weld metal buttering layers

3) Minimise restraint



4) Use pre formed T piece for critical joints

Crack type:

Inter-crystalline corrosion

Location:

Weld HAZ. (Longitudinal)

Steel types:

Stainless steels.

Susceptible microstructure:

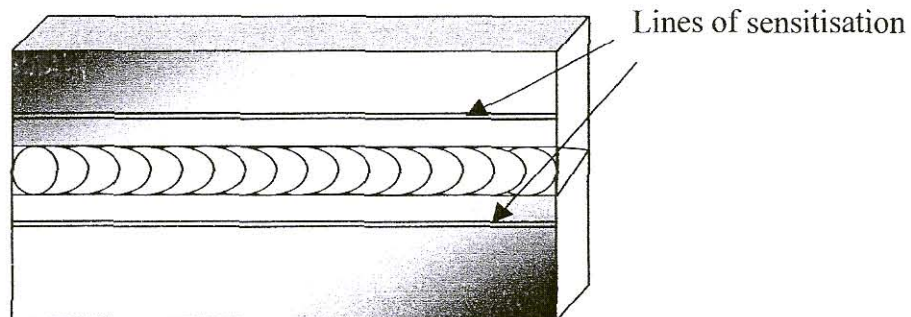
Sensitised grain boundaries.

Causes:

During the welding of stainless steels temperature gradients are met in the HAZ where chromium carbides can be formed from the carbon and chromium. This carbide formation depletes the affected grains of chromium, which will in turn severely reduce corrosion resistance. Immediately after such an effect has occurred we can say that the stainless steel has been **sensitised**, that is to say it has become sensitive to corrosion. If no further treatment is given then corrosion will appear parallel to the weld toes within the HAZ. This corrosion will become more evident when the weld is subsequently put in service. This problem is colloquially known as **weld decay**, although its **occurrence is mainly in the HAZ**. Once initiated, localised pitting may lead to a relatively rapid failure.

Prevention of Sensitisation and Inter-granular corrosion in stainless steels:

- To prevent the occurrence of sensitisation, parent material with a carbon contents below 0.03% C are often used. This reduces the free carbon available to form chromium carbides. For example E316 stainless steel of low carbon content is designated E 316L.
- Elements such as niobium, molybdenum, tantalum, and/or titanium may be added to the base material and electrodes to stabilise the steel. These are termed **stabilising elements**, and tie up any free carbon by forming preferential carbides, thus leaving chromium within the grain, where it will perform its main function in producing chromium oxide, and thus resisting the effects of further corrosion.
- The **association** of chromium and carbon into chrome carbides is very **time/temp** dependant occurring between 600 – 850° C. Most welding procedures are designed to **reduce the time that the HAZ remains within this temperature range**. Therefore it is normal to see **maximum inter-pass temperature** controls applied.
- A sensitised stainless steel may be solution annealed after welding by heating to >1100 °C and cooling rapidly. This dissolves (**disassociates**) the chromium carbide back into solution where rapid cooling will inhibit any re-association.



Summary of Weldability of Steels:

Hydrogen induced HAZ or weld metal cracks

Key words:

Cause:

H₂ HAZ cracks	Process	Consumables	Paint, Rust, Grease
Super saturation	Solubility	σ Concentrations	Low ductility
Diffusion	Transformation	Martensite	Critical factors =
Hardness > 350HV	Hydrogen >15ml	$\sigma > 0.5$ yield stress	Temp < 300 °C

HSLA weld cracks	High strength metal	High C % in weld	Low ductility
Weld contraction	Transverse crack	Micro alloy Nb T V	Longitudinal σ

Prevention Low Alloy and HSLA steels

Pre-heat	Short stable arcs	Prompt PWHT	Use low H ₂ process
Minimise restraint	Remove coatings	Stable arc length	γ S/S weld metal
Reduce σ concentration	Use low Ceq plate	Use hot pass ASAP	Bake basic fluxes

Solidification cracking in C/Mn steels

Keywords:

Cause:

High d:w	Fe/Sulphides	Weld centreline	Contraction
Low melting point film	Contractional forces	Loss of cohesion	Hot shortness

Prevention:

High manganese %	Use low restraint	Control carbon %	Use low dilution
Control heat input	Control sulphur %	Change Preparation	Cleaning

Lamellar tearing in C/Mn steels

Key words:

Cause:

Poor ductility	Plastic strain	Sulphur	Micro inclusions
Contraction	Short transverse	Stepped crack	Segregation

Prevention:

NDT for laminations	Through 't' tensile	Buttering layers	Contraction gap
Re-design joint	Forged T piece	Chem. analysis	Control heat input

Inter - crystalline corrosion in stainless steels

Key words:

Cause:

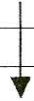
Cr grain depletion	Temp gradient	Cr C Association	Sensitisation
HAZ Parallel to weld	600 -- 850 °C	High carbon content	Time/Temperature

Prevention:

Low Carbon < 0.03%	Max inter-pass temp	Stabilisation	Run sequence
Low heat input	Ti Nb V Ta	Solution annealing	Follow the WPS

WIS 5 Section 22 Exercises:

- 1) Using the key words given overleaf and your understanding write a brief account of:
 - a) The mechanism of H_2 cracking in the HAZ of low alloy steels, indicating the various sources of H_2 and briefly documenting its path to the HAZ and final expulsion from solution?
 - b) How the ***martensitic*** structure is formed in the steel by rapid cooling from austenite?
- 2) Describe the reasons why HSLA steels may suffer from H_2 cracking in the weld metal?
- 3) Describe the various methods used to control H_2 cracking including the use of pre-heats and low hydrogen processes and/or consumables?
- 4) Write a brief account of the mechanism and control methods employed when avoiding:
 - a) Solidification cracking in ferritic and austenitic steels
 - b) Lamellar tearing in steels
 - c) Inter-crystalline corrosion in stainless steels
- 5) From your knowledge of welding processes and consumables list the 4 welding processes for LCS (**Low Carbon Steel**) in the table, as for decreasing levels of *arc H_2* content?
 - a. **FCAW Gas Shielded using a rutile flux cored LCS wire**
 - b. **SAW using a LCS wire with a highly basic *fine mesh* agglomerated flux**
 - c. **TIG using a LCS solid wire with argon shielding**
 - d. **MIG using a LCS solid wire with argon/ CO_2 shielding**

Welding Process	Arc H_2 Content
1 MMA using a LCS Cellulosic electrode (E 6010)	Highest Arc H_2 content
2	
3	
4	
5	
	Lowest Arc H_2 content

- 6) List the 4 ***factors*** associated with occurrence of H_2 cracking, indicating critical values?
 - a. _____
 - b. _____
 - c. _____
 - d. _____

WIS 5 Welding Inspection

Section 23a

The Practice of Visual Welding Inspection

Practical Visual Inspection: (Prepared for CSWIP 3.1 Examination)

The **CSWIP** (Certification Scheme for Welding & Inspection Personnel) examination scheme for welding inspectors consists at present of the following categories:

CSWIP 3.0 Visual Welding Inspector

CSWIP 3.1 Welding Inspector

CSWIP 3.2 Senior Welding Inspector

The CSWIP 3.0 3.1 and AWS CWI – CSWIP 3.1 Bridge examination contents and respective timings are given below:

Exam	Time
CSWIP 3.0	
Practical butt welded butt joint in plate (Code provided)	1hour 45 minutes.
Practical fillet welded T joint in plate (Code provided)	1hour 15 minutes.
Total time:	3 hours
<u>CSWIP 3.1</u>	
<u>Practical butt welded butt joint in plate (Code provided)</u>	1hour 15 minutes.
<u>Practical butt welded butt joint in pipe (Nominated code*)</u>	1hour 45 minutes.
<u>Practical assessment of 2 macros (Code provided)</u>	45 minutes.
<u>Theory Specific. (4 from 6 narrative questions)</u>	1 hour 15 minutes.
<u>Theory General. (30 Multi choice questions)</u>	30 minutes.
<u>Oral. (Questions on code and general inspection)</u>	15 minutes.
Total time:	5hours 45 minutes

* Nominated code is supplied by the candidate

AWS CWI – CSWIP 3.1 Bridge

Practical butt welded butt joint in pipe (Code provided)	1hour 45 minutes.
Practical assessment of 1 macro (Code provided)	25 minutes.
Theory Specific. (1 long + 9 short narrative questions)	1 hour 20 minutes.
Total time:	3 hours 30 minutes

Conditions for Visual Inspection:

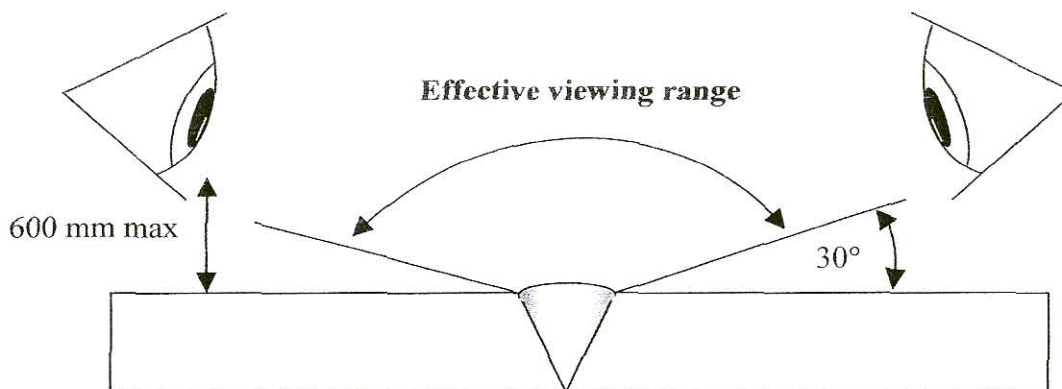
The conditions for visual inspection can be affected mainly by the following:

- 1) **Lighting.**
- 2) **Angle and distance of viewing.**

Light: It is essential that there is adequate illumination (lighting) present during inspection and that the access and angle of viewing are suitable. BS EN 970 states that the minimum light conditions shall be 350 lux, but recommends 500 lux (similar to normal shop or office lighting). 500 lux is also the accepted minimum light level for CSWIP Welding Inspection examinations.

Angle and Distance: BS EN 970 also states that viewing conditions for direct inspection shall be within 600mm of the surface and the viewing angle (line from eye to surface) to be not less than 30°

It will be fairly obvious that increasing distance from an object will impair the ability to identify smaller areas of interest with any clarity, though it can also occur that too close a distance can detract from the overall picture of the weld. For general visual inspection of welds there is generally an optimum viewing range of 150 – 500 mm where inspection can comfortably be carried out. Optical viewing devices such as magnifying lenses may be used during inspection to aid observation though the level of magnification allowable is generally given in the applied standard. In BS EN 970 the limits are set from 2x – 5x magnification.



It should also be remembered that it is very good practice to carry out visual inspection using a variety of viewing angles as some imperfections particularly mechanical damage can only be identified when viewed in reflected light.

This can be most easily seen when using the plastics training replicas supplied during the course and the CSWIP practical examination where it is advisable to view all surfaces in **reflected light**, as it is often difficult to observe slight mechanical damage such as light grinding marks, or a slightly corroded surface when viewing only at 90°

For a candidate to make a respectable attempt at any practical inspection parts of the CSWIP examination he/she will need to be in possession of a number of important items at the exam the venue:

- 1) Good close vision acuity. (Keen eyesight)
- 2) Specialist Gauges and useful hand tools i.e. Torch, mirror, graduated scale etc
- 3) **Nominated Specification if applicable.** Pencil/pen, and a watch
- 4) All examination report forms for the practical exams i.e. Macro/Pipe/Plate
(Supplied to the candidate by the CSWIP exam invigilator)

1) Good Close Vision Acuity

To effectively carry out visual inspection a qualified CSWIP 3.1 Welding Inspector should possess close vision acuity of an acceptable minimum level, thus a test certificate of close vision acuity must be provided before examination in any CSWIP Welding Inspection, or NDT subject. It is also sometimes very important for an inspector to distinguish between contrasting colours in order to effectively interpret results of colour contrast penetrant, fluorescent penetrant and fluorescent magnetic particle inspection tests. Therefore all candidates for CSWIP examinations must also submit a colour blindness test certificate for the effected colours. Any vision certification dated over 6 months previous to the exam date will not be acceptable to the CSWIP management board as any proof of the welding inspectors current vision abilities. All inspectors should be aware of the sudden decay of human visual abilities and should make every effort to attend a vision test at least twice yearly. Inspectors who use optical devices should regularly check that their aided eyesight has not further deteriorated below limits.

2) Specialist Gauges

A number of specialist gauges are available to measure the various elements that need to be measured in a welded fabrication including:

- a) Hi – Lo gauges, for measuring mismatch between pipe walls.
- b) Fillet weld profile gauges, for measuring fillet weld face profile and sizes.
- c) Angle gauges, for measuring weld preparation angles.
- d) Multi functional weld gauges, used to measure many weld values. Page 23.4/ 23.5

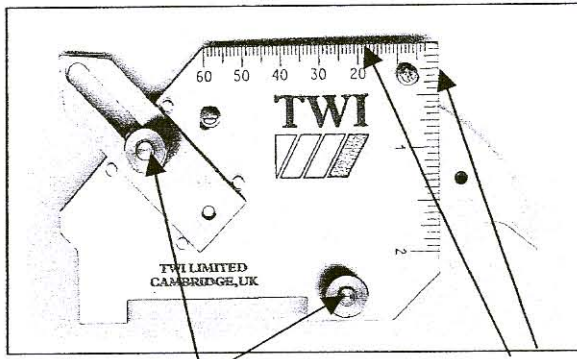
Types of gauges, their measuring ranges and accuracy are also detailed in **BS EN 970**

3) Nominated Specification

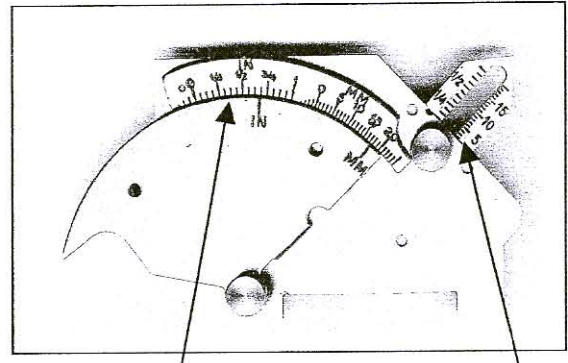
A full list of current applicable codes/standards/specifications for use during the practical pipe examination is given on Pages 18/19 of the CSWIP Doc CSWIP – WI – 6 – 92. Any relevant standard not listed may be presented for clearance/approval prior to the exam by submission to the CSWIP co-ordinator, giving **sufficient time** for this procedure.

THE TWI CAMBRIDGE MULTI-PURPOSE WELDING GAUGE

A tool used in the close estimation of weld dimensions (*Accuracy limitations*)

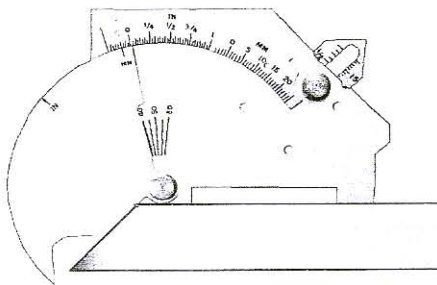


Adjusting screws. Linear scale (Root face/gap)



Radial Scale. Linear Scale (Fillet throat)

Linear and radial scales are given in mm and inches, with angles measured in degrees.

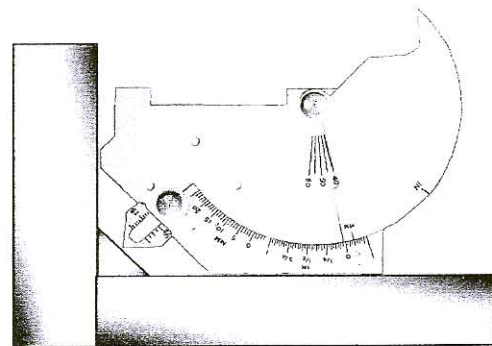


Angle of Preparation

This scale reads 0° to 60° in 5° steps.
The angle is read against the chamfered edge of the plate or pipe.

Fillet Weld Actual Throat Thickness

The small sliding pointer reads up to 20mm, or ¾ inch. When measuring the throat it is supposed that the fillet weld has a '**nominal**' design throat thickness, as '**effective**' design throat thickness cannot be measured in this manner.

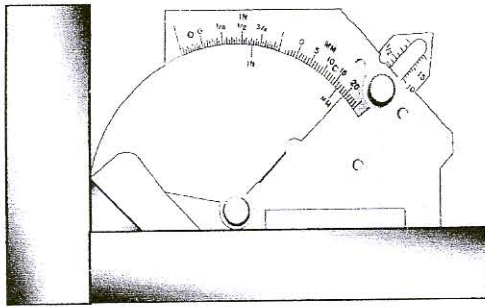


Excess weld metal can be readily calculated by measuring the **Leg Length**, then multiplying by **0.7**

This value is **subtracted** from the measured **Throat Thickness** = **Excess Weld Metal**.

Example: For a measured Leg Length of 10mm and Throat Thickness of 8 mm

$$\therefore 10 \times 0.7 = 7 \quad \therefore 8 - 7 = 1 \text{ mm of Excess Weld Metal.}$$

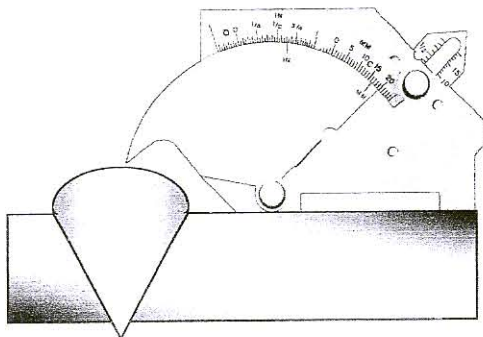
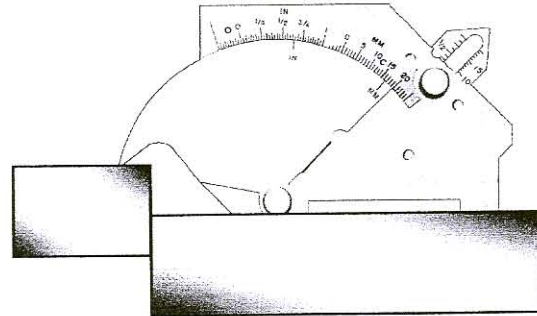


Fillet Weld Leg Length

The gauge may be used to measure fillet weld leg lengths < 25mm as shown.

Linear Misalignment

The gauge may be used to measure misalignment of members by placing the edge of the gauge on the lower member and rotating the segment until the pointed finger contacts the higher member.

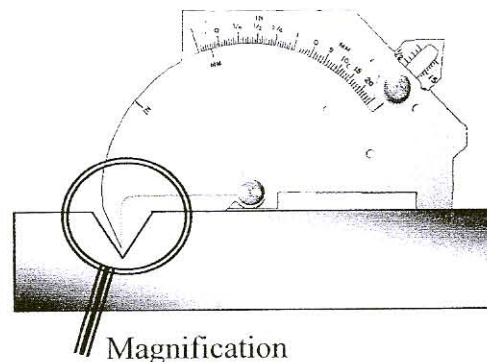


Excess Weld Metal/Root penetration

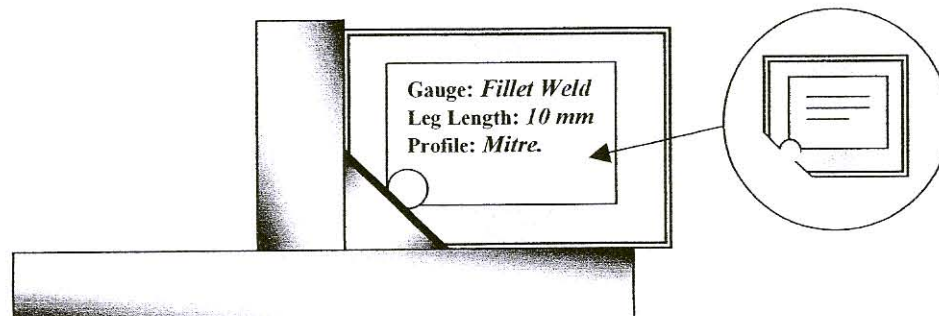
The scale is used to measure excess weld metal height or root penetration bead height of single sided butt welds, by placing the edge of the gauge on the plate and rotating the segment until the pointed finger contacts the excess weld metal or root bead **at its highest point**.

Undercut

The gauge may be used to measure undercut by placing the edge of the gauge on the plate and rotating the segment until the pointed finger contacts the furthest depth of the undercut. The reading is taken in the - scale (left of zero) in mm or inches.



Fillet weld leg length size & profile gauge



4) Visual Examination Report Forms

The requirement for examination records/inspection reports will vary according to contract and type of fabrication and there may not always be a need for a formal record. When a record is required it may be necessary to show that items have been checked at the specified stages and that they have satisfied the acceptance criteria. The form of this record will vary; possibly a signature against an activity on an Inspection Check List or Quality Plan or an individual report for an item. For individual inspection reports, BS EN 970 lists typical details for inclusion as:

- | | |
|---|---------------------------------|
| a) Name of the component manufacturer | b) Examining body, if different |
| c) Identification of the object examined | d) Material |
| e) Type of joint | f) Material thickness |
| g) Welding process | h) Acceptance criteria |
| i) Imperfections exceeding the acceptance criteria and their location | |
| j) Extent of examination with reference to drawings as appropriate | |
| k) Examination devices used | |
| l) Result of examination with reference to acceptance criteria | |
| m) Name of examiner/inspector and date of examination. | |

When it is required by contract to produce and retain permanent visual records of a weld as examined, photographs, accurate sketches, or both should be made with any imperfections clearly indicated.

In the CSWIP 3.1 examination of plate/pipe, 3 report sheets are provided as follows:

Plate or Pipe

Page 1 of 3: Details of weld and a dimensioned sketch of imperfections found within plate/pipe surface and weld face area.

Plate or Pipe

Page 2 of 3: A dimensioned sketch of imperfections found within the plate/pipe weld root area. **Note:** Inspection should include surface areas of the plate/pipe on weld face and weld root sides only and any observations recorded on the relevant sheet. Inspection should always be made from edge to edge.

Plate or Pipe

Page 3 of 3: A final report form containing all relevant information from sheets 1 & 2, then a comparative assessment of the recorded imperfections with the supplied acceptance criteria. Any additional comments should be made of the reverse side of this sheet as directed.

All information (other than sketches) should be completed in ink only.

Note that the datum points on sheets 1 and 2 supplied for the pipe inspection are quartered and identified as **A – B – C – D – A** (Pages 23.12/13)

Pages 23.8 – 23.13 contain examples of completed inspection forms, as if using the set of acceptance criteria given below. This has also been provided for the evaluation part of your **macro** and **plate** inspection practice.

All CSWIP 3.1 candidates should use their **nominated code** wherever possible (for both plate and pipe inspection practice) to gain as much familiarity as is possible with their code prior to the CSWIP examination.

For Training Purposes Only

WIS 5 Acceptance Levels for Butt Welded Plate & Macrograph Inspection/Evaluation

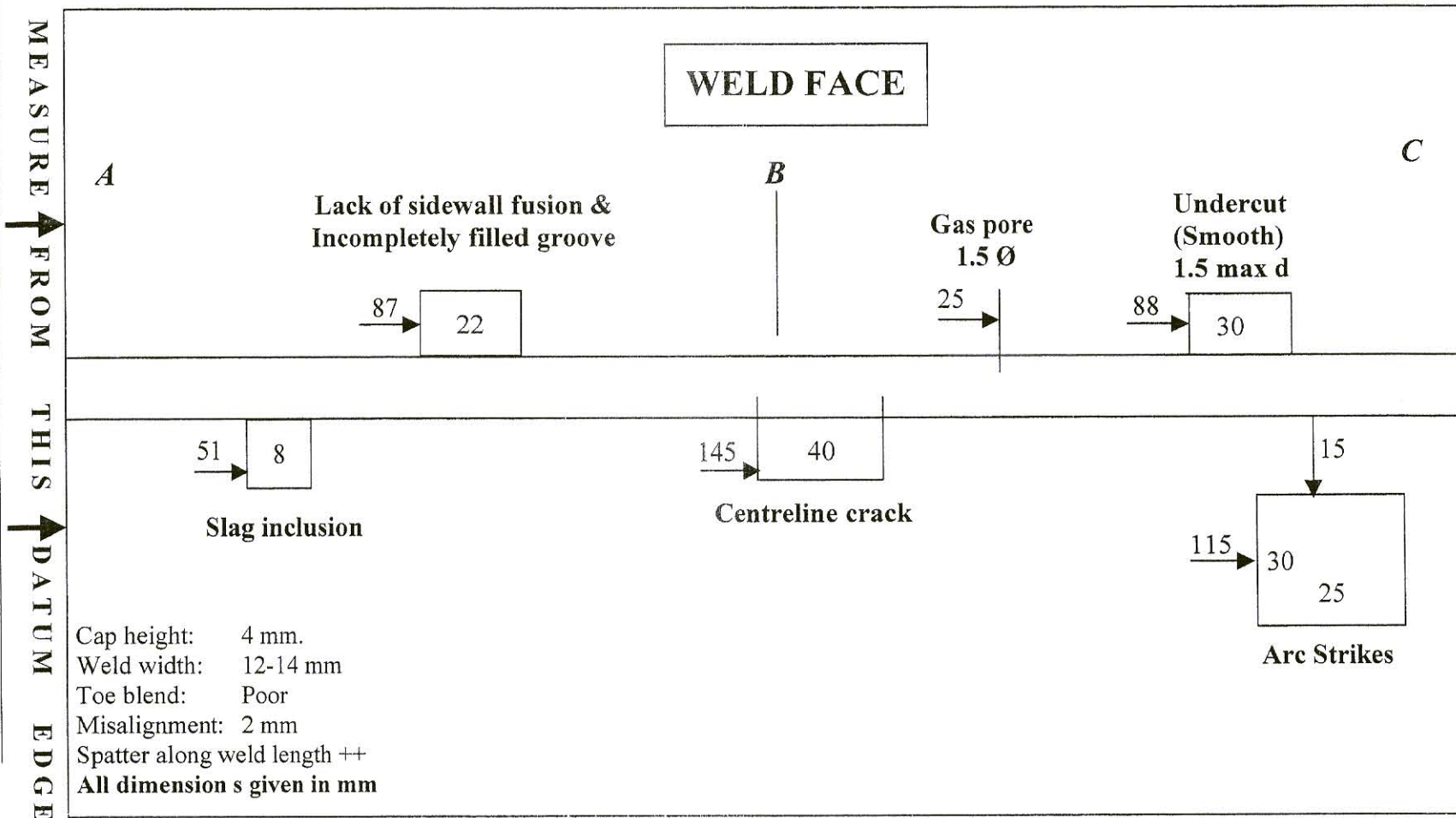
Specification Number TWI 09-09-05

All dimensions are given in millimetres

Key: $\varnothing$ = diameter. t = plate thickness. d = depth. h = height

No	Imperfection	Comments	Allowance
1	Cracks	Confirm with penetrant testing	Not permitted
2	Porosity	Individual gas pore $\varnothing$	Maximum 1mm
3	Solid Inclusions	Non-metallic. Individual size	Maximum 1mm
4	Solid Inclusions	Metallic.	Not permitted
5	Lack of Fusion	Sidewall/Root/Inter-run	Not permitted
6	Incomplete Root Penetration		Not permitted
7	Overlap/Cold lap	Weld face/Root	Not permitted
8	Incompletely filled groove		Not permitted
9	Linear Misalignment		0.2t Maximum 4mm
10	Angular Misalignment		Maximum 10°
11	Undercut	<i>Smoothly blended</i>	10%t Maximum d 1mm
12	Arc Strikes	Test for cracks using MPI	Seek advice for repair
13	Laminations		Not permitted
14	Mechanical Damage	Surfaces shall be free of all <i>rust/scale</i>	Not permitted
15	Cap Height	Shall not fall below plate surface	Maximum h 3mm
16	Penetration Bead	Burn-through not permitted	Maximum h 2mm
17	Spatter	Clean & Re-inspect	Refer to manufacturer
18	Weld Appearance	All toes shall <i>blend smoothly</i>	Regular along the length
19	Root concavity		10%t Maximum d 1mm

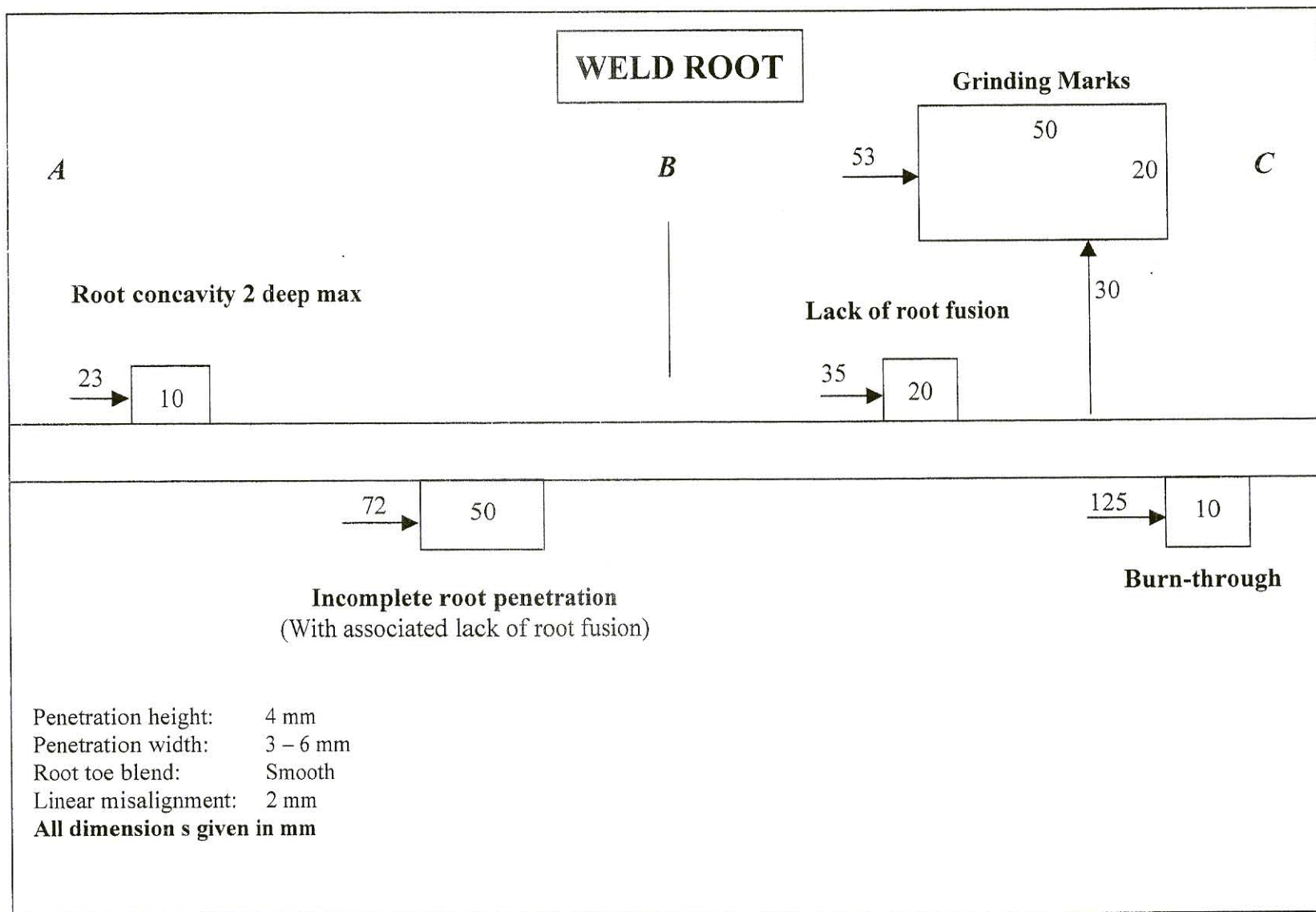
Length & thickness of plate: 300mm x 10 mm **Date** 09-09-05



EXAMPLE PLATE REPORT



MEASURE
 ↓
 FROM
 THIS
 ↓
 DATUM
 EDGE



Weld Report Sheet:

Page 3 of 3

EXAMPLE WELD INSPECTION REPORT/SENTENCE SHEET

PRINT FULL NAME **I C Plenty**

SPECIMEN NUMBER **001**
Face Defects

EXTERNAL DEFECTS	Defects Noted				Code or Specification Reference	
	Defect Type	Accumulative Total	Maximum Allowance	Section/ Table N°	Accept/Reject	
1	2	3	4	5		
Reinforcement (Height)	4 mm	3 mm	15	Reject		
Reinforcement (Appearance)	Poor toe blend	Smooth toe blend	18	Reject		
Incomplete filling	22 mm	Not permitted	8	Reject		
Slag Inclusions	8 mm long	1 mm	3	Reject		
Undercut	1.5 mm depth	1 mm	11	Reject		
Surface Porosity	1.5 mm Ø	1 mm Ø	2	Reject		
Cracks	40 mm	Not permitted	1	Reject +		
Lack of fusion	22 mm	Not permitted	5	Reject		
Arc strikes	30 mm x 25 mm	Test with MPI	12	Seek advice +++		
Mechanical damage	NONE	-----	-----	Accept		
Misalignment	2 mm (Linear)	0.2 t = 2mm	9	Accept		

Root Defects

Misalignment	2 mm (Linear)	0.2 t = 2mm	9	Accept
Penetration (Height)	4 mm	2 mm	16	Reject
Incomplete Root Penetration	50 mm	Not permitted	6	Reject
Lack of Root Fusion	70 mm	Not permitted	5	Reject
Root Concavity	2 mm depth	1 mm max	19	Reject
Root Undercut	NONE	-----	-----	Accept
Cracks	NONE	-----	-----	Accept
Mechanical damage	50 mm x 20 mm	Not permitted	14	Reject
Porosity	NONE	-----	-----	Accept
Burn-through	10 mm length	Not permitted	16	Reject

This *~~pipe~~/plate has been examined to the requirements of code/specification TWI 09-09-05 and is *~~accepted~~/rejected accordingly.

Signature..... *I C Plenty* Date..... **9th September 2005**

*Delete which is not applicable.

Use the other side for any comments.

Comments:

- + **Request** Penetrant NDT testing to confirm crack and true length.
- ++ **Large amount of spatter on weld face. Recommend** cleaning, then re-inspection.
- +++ **Recommend** arc strikes are ground flush prior to MPI testing for crack detection. Seek advice on repair upon test results.

This completes the practical Butt Welded Plate Butt Joint Inspection Assessment.

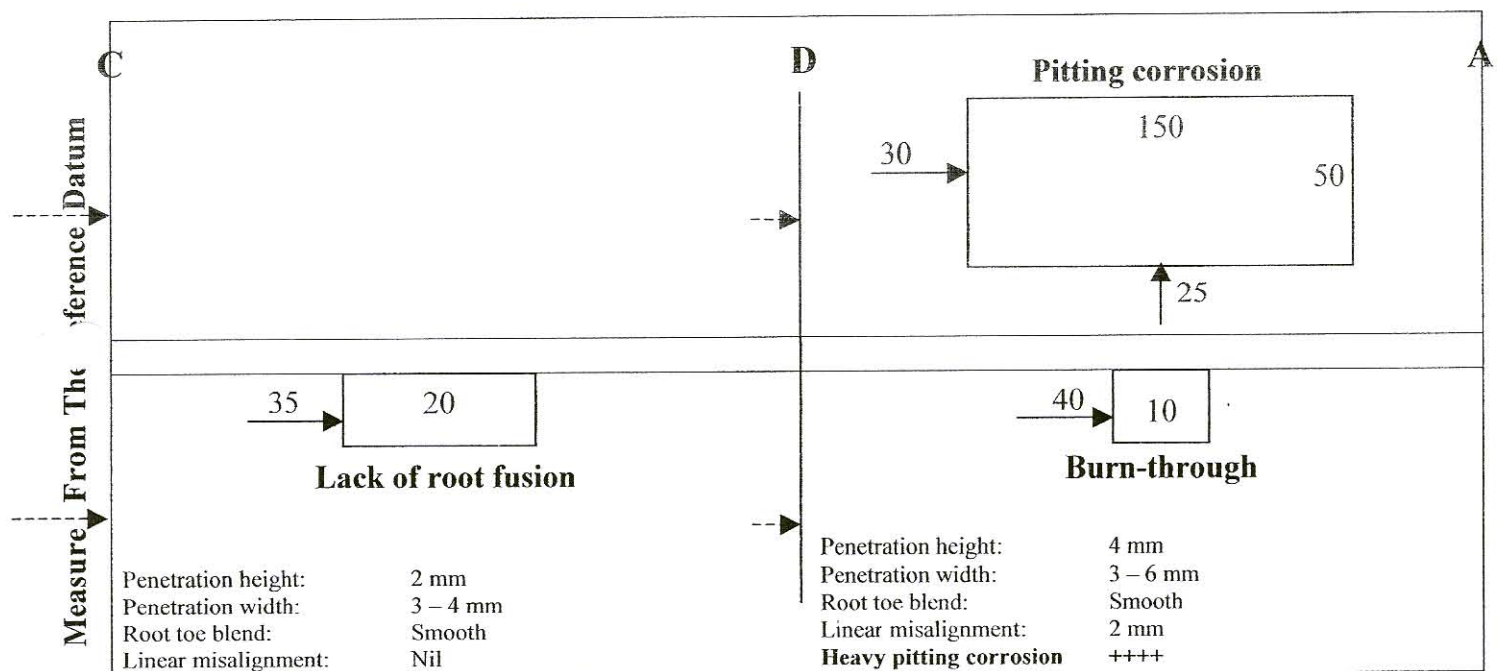
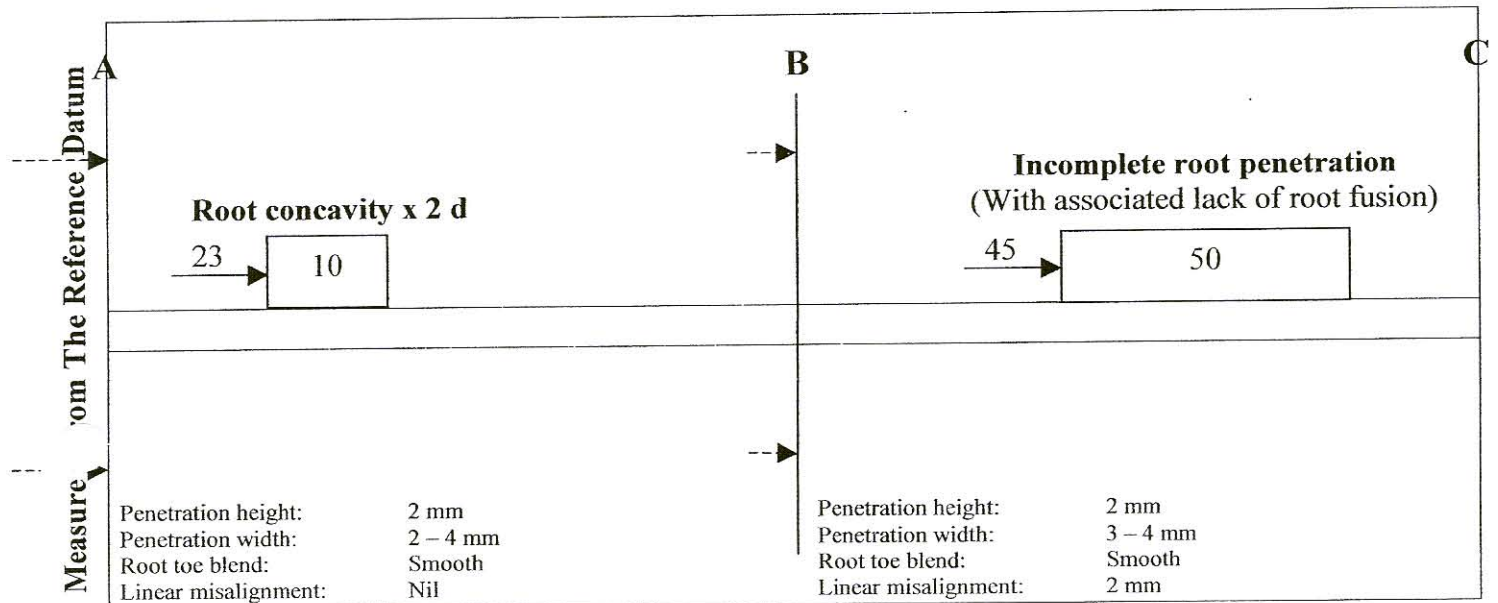
**VISUAL INSPECTION PIPE REPORT**Name [Block capitals] I C PLENTY Signature *I C Plenty* Pipe Ident# XL 001Code/Specification used TWI 09-09-05 Welding Process MMA 111 Joint type V ButtWelding position HLO 45 Outside Ø & Thickness 300 x 15 Date 09-09-05**WELD FACE**

	A	B	C
Datum →	Lack of sidewall fusion and incompletely filled groove		Gas pore 1.5 Ø
	87 → 22	69 →	
Measure From The Reference →	100 → 40	75 → 60 25	15 ↓
	Cap height: 3 mm Weld width: 12-14 mm Toe blend: Smooth Misalignment: Nil Spatter along weld length ++	Centreline crack Cap height: 3 mm Weld width: 12-14 mm Toe blend: Smooth Misalignment: 2 mm	Grinding marks

	C	D	A
Datum →	Undercut (Smooth) 1.5 d max		Slag Inclusion
	65 → 30	52 → 8	
Measure From The Reference →			15 ↓
	Cap height: <u>4 mm</u> Weld width: 12-14 mm Toe blend: Poor Misalignment: Nil	Cap height: 2 mm Weld width: 12-14 mm Toe blend: Poor Misalignment: 2 mm Spatter along weld length ++	110 → 30 35 Arc Strikes

Key:**d = depth****Ø = diameter****All measurements are given in mm****P.T.O. [FOR ROOT]**

WELD ROOT



Key:

d = depth

All measurements are given in mm

Weld Report Sheet:

EXAMPLE WELD INSPECTION REPORT/SENTENCE SHEET

PRINT FULL NAME **I C Plenty**

SPECIMEN NUMBER **XL 001**

Face Defects

EXTERNAL DEFECTS	Defects Noted	Code or Specification Reference		
Defect Type	Accumulative Total 2	Maximum Allowance 3	Section/ Table N° 4	Accept/Reject 5
Reinforcement height	4 mm	3 mm	15	Reject
Reinforcement appearance	Poor toe blend	Smooth	18	Reject
Incomplete filling	22 mm	Not permitted	8	Reject
Slag Inclusions	8 mm length	1 mm	3	Reject
Undercut	1.5 mm depth	1 mm	11	Reject
Surface Porosity	1.5 mm Ø	1 mm Ø	2	Reject
Cracks	40 mm	Not permitted	1	Reject +
Lack of fusion	22 mm	Not permitted	5	Reject
Arc strikes	30 mm x 25 mm	Test with MPI	12	Seek advice +++
Mechanical damage	60 mm x 25 mm	Not permitted	14	Reject
Misalignment (Linear)	2 mm	0.2 t = 2mm	9	Accept

Root Defects

Misalignment (Linear)	2 mm (liner)	0.2 t = 2mm	9	Accept
Penetration (Height)	4 mm	2 mm	16	Reject
Incomplete Root Penetration	70 mm	Not permitted	6	Reject
Lack of Root Fusion	20 mm	Not permitted	5	Reject
Root Concavity	2 mm depth	1 mm	19	Reject
Root Undercut	NONE	-----	-----	Accept
Cracks	NONE	-----	-----	Accept
Mechanical damage	NONE	-----	-----	Accept
Porosity Pitting Corrosion	150 mm x 50 mm	Not permitted	14	Reject ++++
Burn-through	10 mm	Not permitted	16	Reject

This ~~*pipe/plate~~ has been examined to the requirements of code/specification TWI 09-09-05 and is ~~*accepted/rejected~~ accordingly.

Signature I C Plenty Date 9th September 2005

***Delete which is not applicable.**

Comments:

- + Request Penetrant NDT testing to confirm crack and true length
- ++ Large amount of spatter on weld face. Recommend this is removed and re-inspected
- +++ Recommend arc strikes are ground flush prior to MPI testing for crack detection. Seek advice on repair upon test results
- ++++ Heavy pitting corrosion 150 x 50 mm. Remove scale, brush clean, then re-inspect.

This completes the practical Butt Welded Pipe Butt Joint Inspection Assessment.