

A large blue abstract graphic spanning the width of the page. It features a faint world map in the background, overlaid with several horizontal and diagonal bands of varying shades of blue, creating a sense of depth and movement.

CSWIP 3.2 – Senior Welding Inspector WIS10

Training and Examination Services
Granta Park, Great Abington
Cambridge CB21 6AL
United Kingdom

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CSWIP 3.2 Senior Welding Inspection

WIS10

Materials Joining and Engineering Technologies
Training and Examination Services

TWI **CSWIP 3.2 Senior Welding Inspector**

Introduction

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TWI **The Course**

- The Senior Welding Inspector course covers a variety of subjects that somebody operating at this level will have to have a comprehensive knowledge of.
- Once each subject is presented it will be reinforced with 10 questions relating to that subject. As the examination is multi choice these questions will also be.

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TWI **Course Subjects**

- QA and QC
- Destructive testing
- Heat treatments
- Welding procedures
- Welding dissimilar
- Residual stress and distortion
- Weldability
- Weld fractures
- Welding symbols
- Non destructive testing
- Welding consumables
- Weld repairs
 - Specifications
 - Joint design
 - HSLA steels
 - Arc energy and heat input

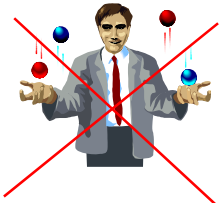
There will also be homework each night in multi choice format which will be reviewed the following day.

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TWI **Course Assessment**

Exam after the course is completed

No continuous assessment

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TWI **CSWIP Certificate Scheme**

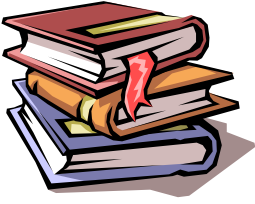
- 3.0 Visual Welding Inspector
- 3.1 Welding Inspector
- 3.2 Senior Welding Inspector
- For further examination information please see website www.cswip.com



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CSWIP 3.2 Examination



- The TWI Specification will be used.
- To attempt the Senior Welding Inspectors Examination (3.2) you must already be a holder of the Welding Inspectors Qualification (3.1).

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CSWIP 3.0 Examination

Before attempting the examination, you **MUST** provide the following

- Two passport size photographs, with your name and signature on reverse side of both.
- Eye test certificate, the certificate must show near vision and colour tests. (N4.5 or Times Roman numerals standard) and verified enrolment.
- Completed examination form, you can print from the website www.twi.training.com

It is the sole responsibility of the candidate to provide the above. Failure to do so will delay results and certification being issued.

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CSWIP 3.2 Examination

- **3.2.1 Without radiograph interpretation**
70% pass mark required in all areas of examination
- **3.2.2 With radiograph interpretation (Optional)**
70% Pass mark required in all areas of examination including radiographic interpretation before certificate can be issued.

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CSWIP 3.2 Examination

There are **four sections** to the examination each will require 70% pass mark for the qualification to be awarded.

- Part 1 General Multi-choice **30 Questions**
45 minutes
- Part 2 Scenario multi choice **60 questions**
150 minutes
- Part 3 Assessment of four NDT Reports **40 Questions**
75 minutes
- Part 4 The interpretation of weld symbols using a drawing **10 questions**
30 minutes

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CSWIP 3.2 Examination

All of the questions from all of the sections are generated individually from a large data base so no one student has the same exam.

In the case of the scenario section of 60 questions, 12 topics will be randomly generated, each with 4 questions from the 12 sections presented through the week and 12 questions directly related to the specification.

The exam specification, will be required for most of the scenario and NDT questions but not for the General and weld symbol questions.

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CSWIP 3.2 Examination

For candidates wishing to complete the RT supplementary examination

- Theory B2: Radiographic general theory **20 multiple-choice questions** 30 Minutes
- Theory: Density and Sensitivity Calculations 1 hour
- Practical D2: Interpretation of Radiographs
- Metal Group A: Ferrous **6 Radiographs** 1 Hour 30 Minutes
- Metal Group B: Austenitic **3 Radiographs** 45 Minutes
- Metal Group C: Aluminum **3 Radiographs** 45 minutes
- Metal Group D: Copper **3 Radiographs** 45 minutes

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Notification of Examination Results



**70% Pass mark
required for
EVERY section
of the exam**



**2 copies of certificates and an identity card
sent to delegates' sponsor**

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CSWIP 3.2 Renewals

5 years

Log book submittal



10 years

Renewal examination



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Certification Scheme for Personnel



Recognised Worldwide

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CSWIP 3.2 – Senior Welding Inspector

Contents

Section	Subject
1	Duties of the Senior Welding Inspector
1.1	Leadership skills
1.2	Technical skills
1.3	Knowledge of technology
1.4	Knowledge of normative documents
1.5	Knowledge of planning
1.6	Knowledge of organisation
1.7	Knowledge of quality/auditing
1.8	Man management
1.9	Recruitment
1.10	Morals and motivation
1.11	Discipline
1.12	Summary
2	Welded Joint Design
2.1	Welds
2.2	Types of joint
2.3	Fillet welds
2.4	Butt welds
2.5	Dilution
2.6	Welding symbols
2.7	Welding positions
2.8	Weld joint preparations
2.9	Designing welded joints
2.10	Summary
3	Quality Assurance and Quality Control
3.1	Definitions
3.2	Quality system standards
3.3	Auditing and documentation
3.4	Quality requirements for welding
3.5	Calibration/validation of welding equipment
3.6	Workshop exercise
4	Codes and Standards
4.1	Company manuals
4.2	Auditing
4.3	Codes and standards
4.4	Summary
5	Fe-C Steels
5.1	Steel terminology
6	Destructive Testing
6.1	Test types, test pieces and test objectives
6.2	Fracture tests
6.3	Macroscopic examination

7	Heat Treatment
7.1	Heat treatment of steel
7.2	Post weld heat treatment (PWHT)
7.3	PWHT thermal cycle
7.4	Heat treatment furnaces
7.5	Local PWHT
8	WPS and Welder Qualifications
8.1	Qualified welding procedure specifications
8.2	Welder qualification
9	Arc Energy and Heat Input
9.1	Current and voltage
9.2	Arc energy or heat input
10	Residual Stress and Distortion
10.1	What causes distortion?
10.2	What are the main types of distortion?
10.3	What are the factors affecting distortion?
10.4	Distortion – prevention by pre-setting, pre-bending or use of restraint
10.5	Distortion – prevention by design
10.6	Elimination of welding
10.7	Distortion – prevention by fabrication techniques
10.8	Distortion – corrective techniques
11	Weldability of Steels
11.1	Factors that effect weldability
11.2	Hydrogen cracking
11.3	Solidification cracking
11.4	Lamellar tearing
12	Weld Fractures
12.1	Ductile fractures
12.2	Brittle fracture
12.3	Fatigue fracture
13	Welding Symbols
13.1	Standards for symbolic representation of welded joints on drawings
13.2	Elementary welding symbols
13.3	Combination of elementary symbols
13.4	Supplementary symbols
13.5	Position of symbols on drawings
13.6	Relationship between the arrow line and the joint line
13.7	Position of the reference line and position of the weld symbol
13.8	Positions of the continuous line and the dashed line
13.9	Dimensioning of welds
13.10	Indicatgion of the welding process
13.11	Other information in the tail of the reference line
13.12	Weld symbols in accordance with AWS 2.4
14	NDT
14.1	Radiographic methods
14.2	Magnetic particle testing
14.3	Dye penetrant testing
14.4	Surface cracks detection (magnetic particle/dye penetrant): general

15	Welding Consumables
15.1	MMA electrodes
15.2	Cellulosic electrodes
15.3	Rutile electrodes
15.4	Basic electrodes
15.5	Classification of electrodes
15.6	TIG filler wires
15.7	MIG/MAG filler wires
15.8	SAW filler wires
16	MAG welding
16.1	The process
16.2	Process variables
16.3	Welding consumables
16.4	Important inspection point/checks when MIG/MAG welding
17	MMA Welding
17.1	Manual metal arc/shielded metal arc welding (MMA/SMAW)
17.2	MMA welding basic equipment requirements
17.3	Power requirements
17.4	Welding variables
17.5	Voltage
17.6	Type of current and polarity
17.7	Type of consumable electrode
17.8	Typical welding defects
18	Submerged Arc Welding
18.1	The process
18.2	Process variables
18.3	Storage and care of consumables
19	TIG Welding
19.1	Process characteristics
19.2	Process variables
19.3	Filler wires and shielding gases
19.4	Tungsten inclusions
19.5	Crater cracking
19.6	Common applications of the TIG process
19.7	Advantages of the TIG process
19.8	Disadvantages of the TIG process
20	Weld Repairs
20.1	Production repairs
20.2	In-service repairs
Appendix 1	Homeworks
Appendix 2	NDT Training Reports
Appendix 3	Training Drawing
Appendix 4	Specification Questions

Section 1
Duties of the Senior Welding Inspector

1 Duties of the Senior Welding Inspector

The Senior Welding Inspector has primarily a supervisory/managerial role, which could encompass the management and control of an inspection contract. The role would certainly include leading a team of Welding Inspectors, who will look to the Senior Welding Inspector for guidance, especially on technical subjects. The Senior Welding Inspector will be expected to give advice, resolve problems, take decisions and generally lead from the front, sometimes in difficult situations.

The attributes required by the Senior Welding Inspector are varied and the emphasis on certain attributes and skills may differ from project to project. Essentially though the Senior Welding Inspector will require leadership skills, technical skills and experience.

1.1 Leadership skills

Some aspects on the theory of leadership may be taught in the classroom, but leadership is an inherent part of the character and temperament of an individual. Practical application and experience play a major part in the development of leadership skills and the Senior Welding Inspector should strive to improve and fine tune these skills at every opportunity.

The skills required for the development of leadership include a:

- Willingness and ability to accept instructions or orders from senior staff and to act in the manner prescribed.
- Willingness and ability to give orders in a clear and concise manner, whether verbal or written, which will leave the recipient in no doubt as to what action or actions are required.
- Willingness to take responsibility, particularly when things go wrong, perhaps due to the Senior Welding Inspector's direction, or lack of it.
- Capacity to listen (the basis for good communication skills) if and when explanations are necessary and to provide constructive reasoning and advice.
- Willingness to delegate responsibility to allow staff to get on with the job and to trust them to act in a professional manner. The Senior Welding Inspector should, wherever possible, stay in the background, managing.
- Willingness and ability to support members of the team on technical and administrative issues.

1.2 Technical skills

A number of factors make up the technical skills required by the Senior Welding Inspector and these are a knowledge of:

- Technology.
- Normative documents.
- Planning.
- Organisation.
- Auditing.

1.3 Knowledge of technology

Welding technology knowledge required by the Senior Welding Inspector is very similar to that required by the Welding Inspector, but with some additional scope and depth.

Certain areas where additional knowledge is required are a:

- Knowledge of quality assurance and quality control.
- Sound appreciation of the four commonly used non-destructive testing methods.
- Basic understanding of steel metallurgy for commonly welded materials and the application of this understanding to the assessment of fracture surfaces.
- Assessment of non-destructive test reports, particularly the interpretation of radiographs.

1.4 Knowledge of normative documents

It is not a requirement for Inspectors at any level to memorise the content of relevant normative documents, except possibly with the exception of taking examinations.

Specified normative documents (specifications, standards, codes of practice, etc) should be available at the workplace and the Senior Welding Inspector would be expected to read, understand and apply the requirements with the necessary level of precision and direction required.

The Senior Welding Inspector should be aware of the more widely used standards as applied in welding and fabrication. For example:

BS EN ISO 15614 / ASME IX	Standards for welding procedure approval
BS 4872, BS EN 287/ BS EN ISO 9606 / ASME IX	Standards for welder approval.
PED BS 5500 / ASME VIII	Standards for quality of fabrication.
BS EN ISO 9000 – 2000	Standards for quality management.

1.5 Knowledge of planning

Any project or contract will require some planning if inspection is to be carried out effectively and within budget.

See Section: Planning for more detailed information.

1.6 Knowledge of organisation

The Senior Welding Inspector must have good organisational skills in order to ensure that the inspection requirements of any quality/inspection plan can be met, within the allocated time, budget and using the most suitable personnel for the activity. Assessment of suitable personnel may require consideration of their technical, physical and mental abilities in order to ensure that they are able to perform the tasks required of them. Other considerations would include availability of inspection personnel at the time required, levels of supervision and the monitoring of the inspector's activities from start to contract completion.

1.7 Knowledge of quality /auditing

There are many situations in manufacturing or on a project where the Senior Welding Inspector may be required to carry out audits.

See section on: Quality Assurance/Quality Control and Inspection for more detailed information.

1.8 Man management

As mentioned above, the Senior Welding Inspector will have to direct and work with a team of Inspection personnel which he may well have to pick. He will have to liaise with customer representatives, sub-contractors and third party Inspectors. He may have to investigate non-compliances, deal with matters of discipline as well as personal matters of his staff.

To do this effectively he needs skills in man management.

1.9 Recruitment

When recruiting an individual or a team the SWI will first have to establish the requirements of the work. Among them would be:

- What skills are definitely required for the work and what additional ones would be desirable?
- Are particular qualifications needed?
- Is experience of similar work desirable?
- What physical attributes are needed?
- Is the work local, in-shop, on-site, in a third world country?
- Does the job require working unsociable hours being away from home for long periods?
- Is the job for permanent staff or for a fixed term?
- If overseas what are the leave and travel arrangements?
- What is the likely salary?

During subsequent interviews the SWI will need to assess other aspects of the candidates' suitability:

- Has he the ability to work on his own initiative?
- Can he work as part of a team?
- If overseas has the person been to a similar location?
- What is his marital/home situation?
- Are there any Passport/Visa problems likely?

1.10 Morale and motivation

The morale of a workforce has a significant effect on its performance so the SWI must strive to keep the personnel happy and motivated and be able to detect signs of low morale.

Low morale can lead to among other things, poor productivity, less good workmanship, lack of diligence, taking short cuts, ignoring safety procedures and higher levels of absenteeism.

The SWI needs to be able to recognise these signs and others such as personnel not starting work promptly, taking longer breaks, talking in groups and grumbling about minor matters.

A good supervisor should not allow his workforce to get into such a state.

He must keep them motivated by:

- His own demeanour – does he have drive and enthusiasm or is he seen to have no energy and generally depressed. The workforce will react accordingly.
- Is he seen to be leading from the front in a fair and consistent manner?
- Favouritism in the treatment of staff, on disciplinary matters, the allocation of work, allotment of overtime, weekend working and holidays are common causes of problems.
- Keep them informed in all aspects of the job and their situation. Rumours of impending redundancies or cuts in allowances etc will not make for good morale.

1.11 Discipline

Any workforce must be working in a disciplined manner, normally to rules and standards laid down in the Company's conditions of employment or relevant company handbook. The SWI must have a good understanding of these requirements and be able to apply them in a fair and equitable manner.

He must have a clear understanding as to the limits of his authority – knowing how far he can go in disciplinary proceedings.

The usual stages of disciplinary procedure are:

- The quiet word.
- Formal verbal warning.
- Written warning.
- Possible demotion, transfer, suspension.
- Dismissal with notice.
- Instant dismissal.

Usually after the written warning stage the matter will be handled by the Company's Personnel or Human Resources Department.

It is of vital importance that the company rules are rigorously followed as any deviation could result in claims for unfair or constructive dismissal.

In dealing with disciplinary matters the SWI must:

- Act promptly.
- Mean what he says.
- Treat everyone fairly and as an adult.
- Avoid constant complaining on petty issues.

Where there are serious breaches of company rules by one or two people the rest of the workforce should be informed of the matter so that rumour and counter-rumours can be quashed.

Some matters of discipline may well arise because of incorrect working practices, passing off below quality work, signing for work which has not been done, etc.

In all such cases the SWI will need to carry out an investigation and apply disciplinary sanctions to the personnel involved.

To do this:

- First establish the facts – by interviewing staff, from the relevant records, by having rechecks on part of the job.
- If any suspicions are confirmed, transfer/remove suspect personnel from the job pending disciplinary proceedings. If the personnel are employed by a sub-contractor then a meeting with the sub-contractor will be needed to achieve the same end.
- Find out the extent of the problem, is it localised or widespread?
- Is there need to inform the customer and third party inspector?
- Formulate a plan of action, with other company departments where necessary, to retrieve the situation.
- Carry out the necessary disciplinary measures on the personnel involved.
- Convene a meeting with the rest of the workforce to inform them of the situation and ensure that any similar lapses will be dealt with severely.
- Follow up the meeting with a written memo.

1.12 Summary

The Senior Welding Inspector's role can be varied and complex, a number of skills need to be developed in order for the individual to be effective in the role. Every Senior Welding Inspector will have personal skills and attributes which can be brought to the job, some of the skills identified above may already have been mastered or understood. The important thing for the individual to recognise is not only do they have unique abilities which they can bring to the role, but they also need to strive to be the best they can by strengthening identifiable weak areas in their knowledge and understanding.

Some ways in which these goals may be achieved is through:

- Embracing facts and realities.
- Being creative.
- Being interested in solving problems.
- Being pro-active not reactive.
- Having empathy with other people.
- Having personal values.
- Being objective.

Section 2

Welded Joint Design

2 Welded Joint Design

This section is principally concerned with structures fabricated by welding steel plates together, examples include bridges, ships, offshore platforms, pressure vessels and pipelines, although in some cases this may involve welding curved plates together.

This section introduces typical joint geometries involved in joining plates together and describes the types of weld used in these joint configurations with typical features of butt and fillet welds described. For the structure to function loads must be transferred from one plate to another and the features of welds that enable them to transmit loads are described. Finally, some examples of good and bad design practice are given.

2.1 Welds

A weld is a permanent union between materials caused by the application of heat, pressure or both and if made between two faces approximately parallel is known as a butt weld.

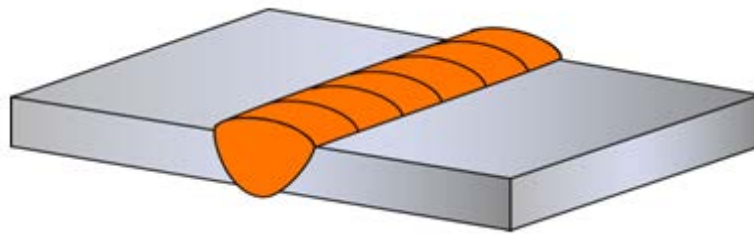


Figure 2.1 Butt weld.

A weld made between two faces that are approximately at right angles to each other is known as a fillet weld.

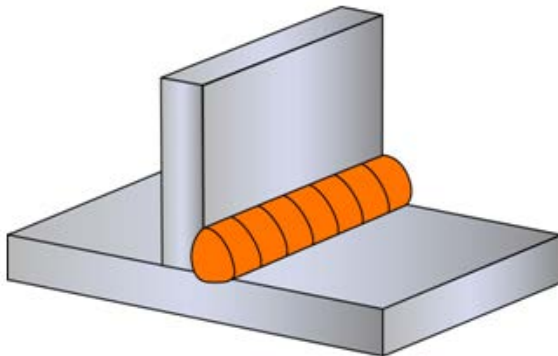


Figure 2.2 Fillet weld.

For simplicity these diagrams show an arc welding process that deposits filler weld metal in a single weld pass. Typical features of a butt weld are shown in Figure 2.3 and those of a fillet weld in Figure 2.4.

The weld or weld metal refers to all the material that has melted and re-solidified. The heat-affected zone (HAZ) is material that has not melted but whose microstructure has been changed as a result of the welding. The fusion line is the interface between the weld metal and the HAZ.

The root is the bottom of the weld or narrowest part and the face is the top or widest part. At the corners of the weld cross section where the weld metal joins the parent metal are the weld toes. These are at each corner of both the weld face and weld root in a butt weld but only on the weld face in a fillet weld.

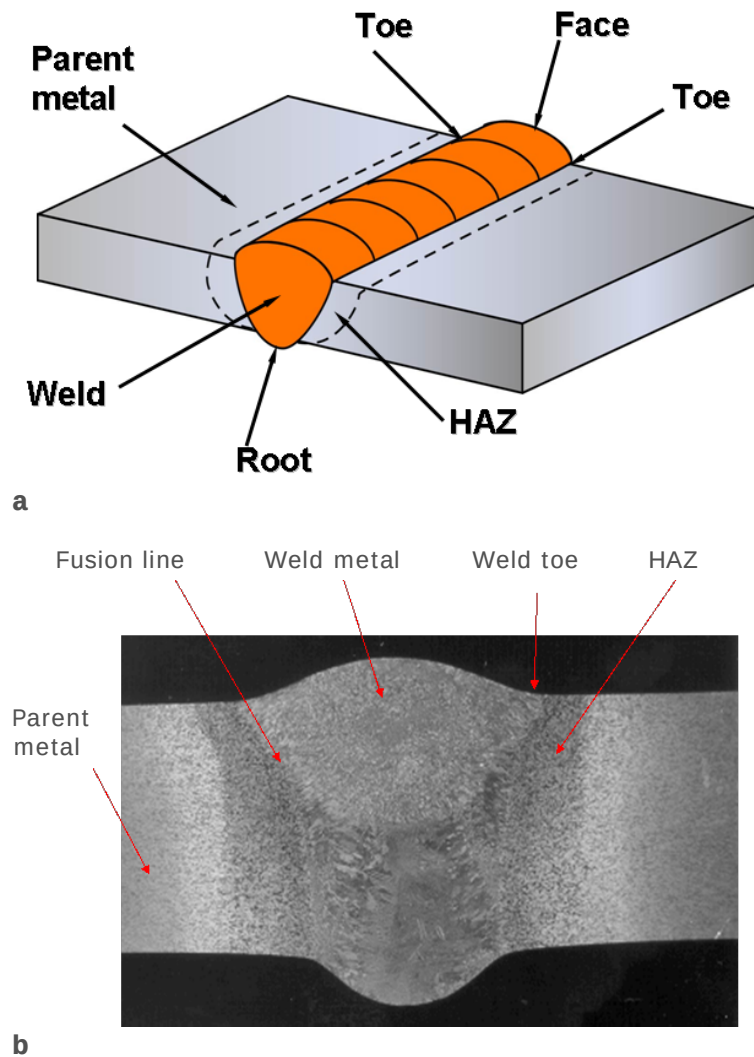


Figure 2.3 Typical features of a:

a Butt weld.

b Double-sided butt weld.

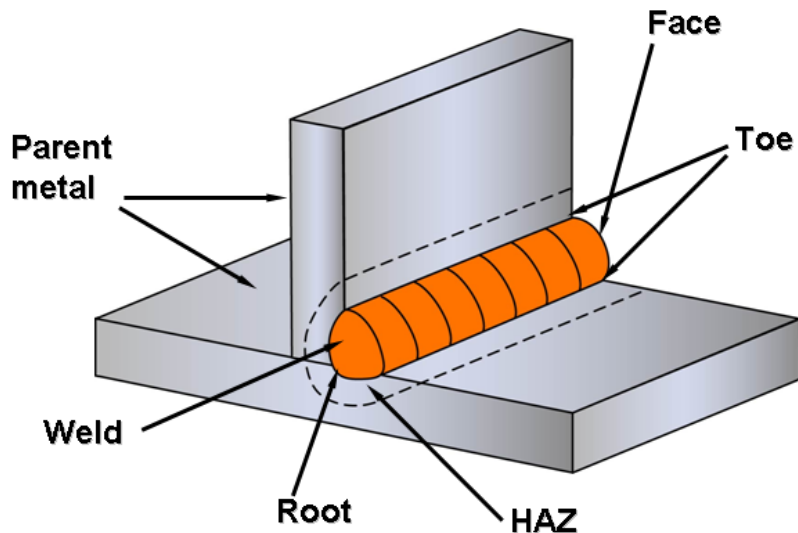


Figure 2.4 Typical features of a fillet weld.

The application of heat naturally causes some changes to the microstructure parent material, the HAZ shown in Figure 2.5 for a butt weld in steel with similar HAZs developed in the parent material of fillet welds. Close to the fusion line the temperature in the HAZ has been sufficient to cause microstructural phase changes, which will result in recrystallisation and grain growth. Further away from the fusion line the parent material has been heated to a lower maximum temperature and the parent microstructure is tempered.

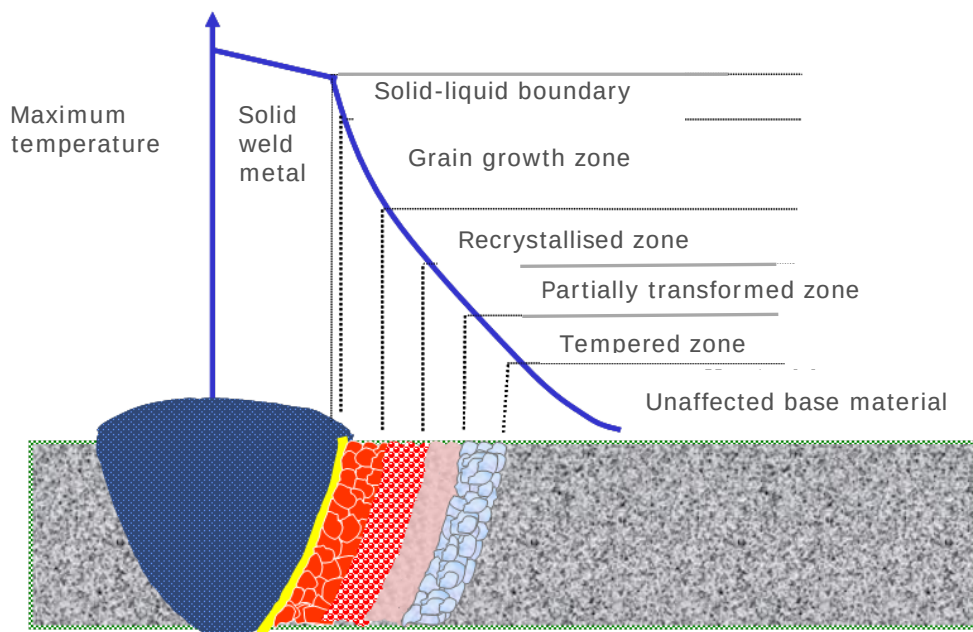


Figure 2.5 HAZs in a butt weld.

The distance between weld toes is the weld width. When the distance is between the toes at the weld cap it is the weld cap width, the distance between the toes at the root is the weld root width.

The height of the additional weld metal in the weld cap is the excess weld metal which used to be called reinforcement which wrongly suggests that increasing this dimension will strengthen the weld. If the excess weld metal is too great it increases the stress concentration at the weld toe and this extra weld metal is called the excess root penetration.

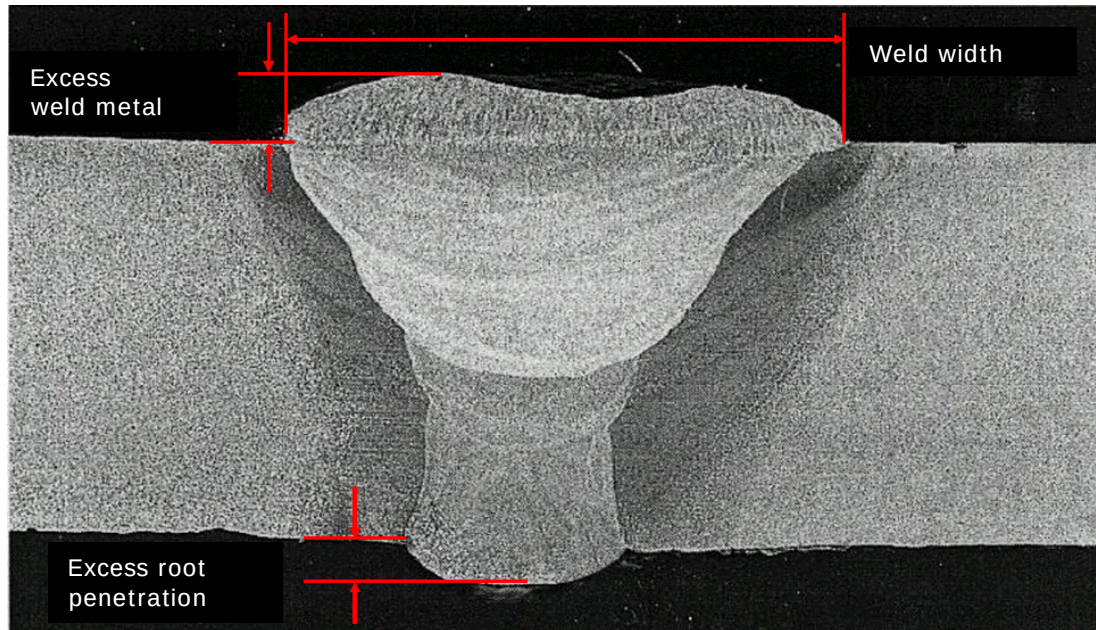


Figure 2.6 Definitions on a butt weld.

2.2 Types of joint

A joint can simply be described as a configuration of members and can be described independently of how it is welded. Figures 2.7 and 2.8 show the most common joint types - butt and T joint. Other typical joint types are shown in Figures 2.9-2.11; lap, cruciform and corner joint. When designing a lap joint the overlap between the two plates needs to be at least four times the plate thickness ($D = 4t$), but not less than 25mm.



Figure 2.7 Butt joint.

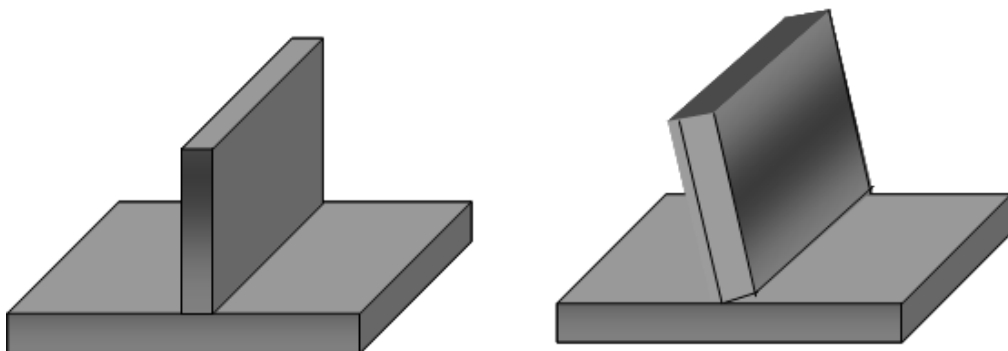


Figure 2.8 T joint.

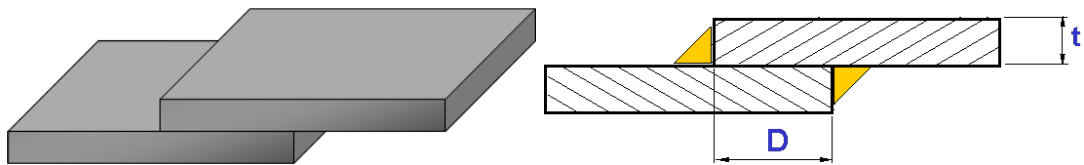


Figure 2.9 Lap joints.

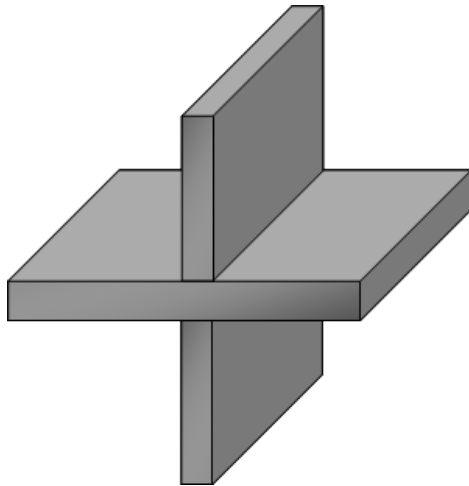


Figure 2.10 Cruciform Joint

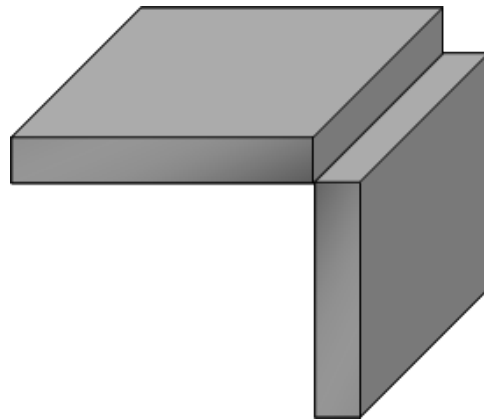


Figure 2.11 Corner joint.

An alternative to a conventional lap joint is to weld the joint using plug or slot welding, shown in Figure 2.12 showing the typical lap joint can be drastically altered. The hole for a slot weld should have a width at least three times the plate thickness and not less than 25mm. In plate less than 10mm thickness, a hole of equal width to the plate thickness can be welded as a plug weld.

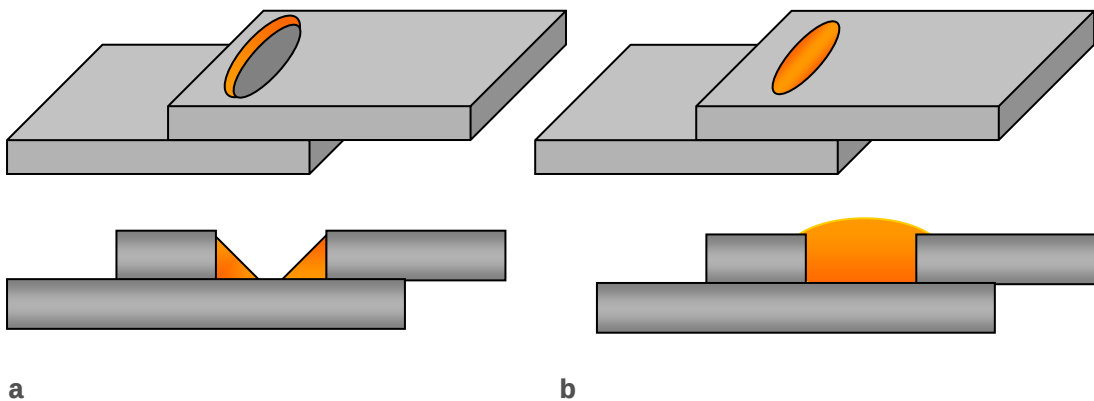


Figure 2.12:

- a Slot welded lap joint.**
- b Plug welded lap joint.**

Corner joints can be fitted and welded in a number of ways. The unwelded pieces can be assembled either with an open corner or closed together. The weld can be on the external or internal corner or both in a double-sided weld.

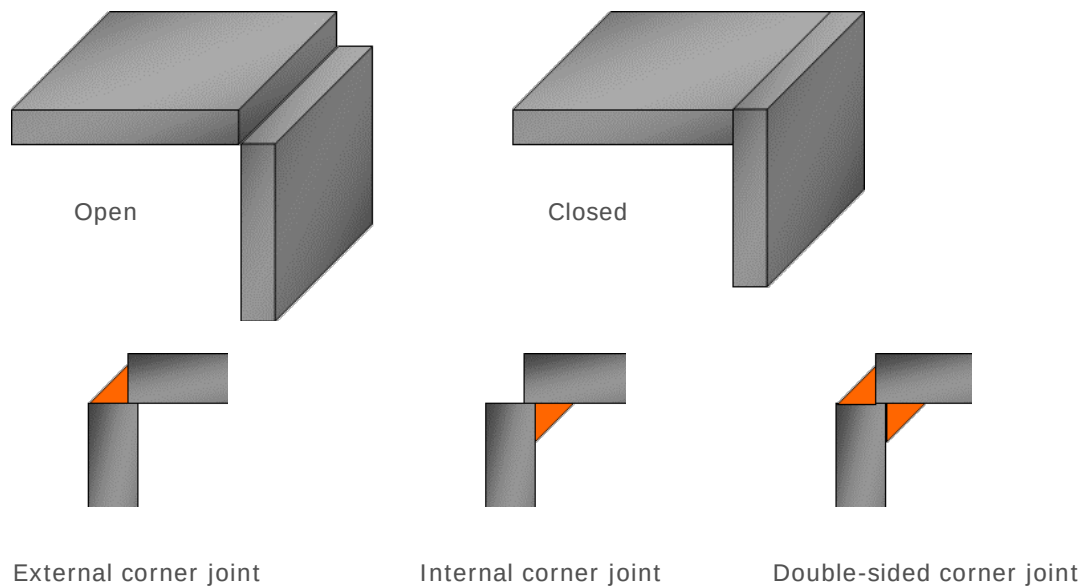


Figure 2.13 Different types of corner joints, unwelded and welded.

2.3 Fillet welds

The throat and leg length of a fillet weld are shown in Figure 2.14. Throat size a is generally used as the design parameter since this part of the weld bears the stresses and can be related to leg length z by the following relationship: $a \approx 0.7z$ and $z \approx 1.4a$.

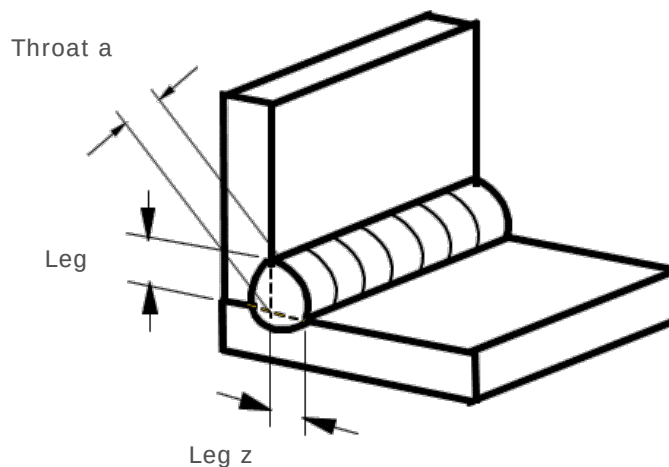


Figure 2.14 Leg length z and throat size a in a fillet weld.

This is only valid for mitre fillet welds having similar leg lengths (Figure 2.15), so is not valid for concave, convex or asymmetric welds. In concave fillet welds the throat thickness will be much less than 0.7 times the length. The leg length of a fillet weld is often approximately equal to the material thickness. The actual throat size is the width between the fused weld root and the segment linking the two weld toes, shown as the red line in Figure 2.16. Due to root penetration the actual throat size of a fillet weld is often larger than its design size but because of the unpredictability of the root penetration area, the **design** throat size must **always** be taken as the stress parameters in design calculations.

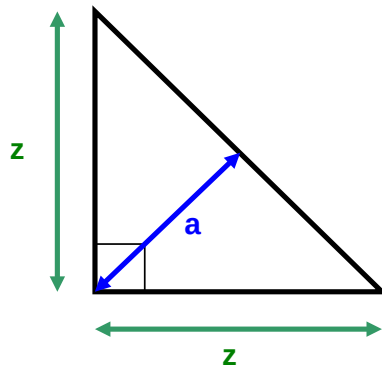


Figure 2.15 Mitre fillet weld.

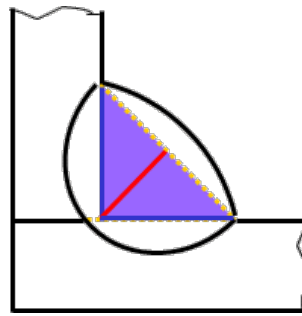


Figure 2.16 Design throat of a fillet weld.

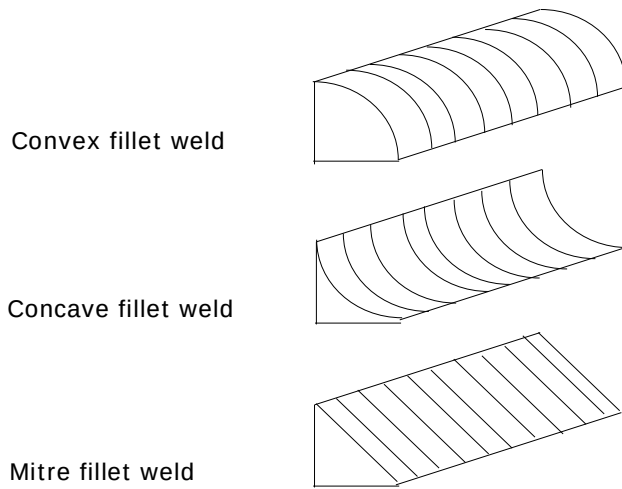


Figure 2.17 Fillet weld cross-sections.

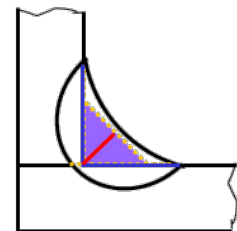
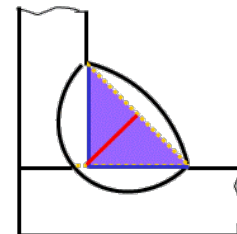
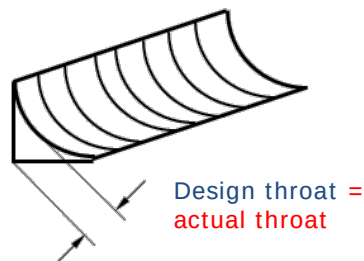
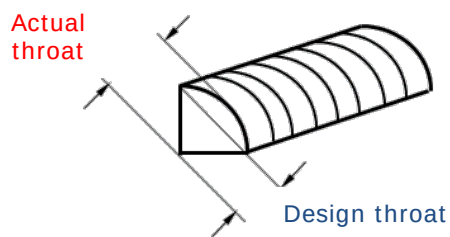


Figure 2.18 Definition of design and actual throat in concave and convex fillet welds.

The choice between mitre weld, concave and convex fillet weld needs to account for the weld toe blend. A concave fillet weld gives a smooth blend profile and a low stress concentration at the fillet weld toe. Convex fillet welds can have a higher stress concentration at the weld toe. If the fluidity of the weld pool is not controlled it is possible to obtain an asymmetrical fillet weld where the weld pool has sagged into the joint preparation and there is also a risk of undercut on the bottom weld toe (see Figure 2.19). Having a smooth toe blend is important to give better fatigue performance for fillet welds.

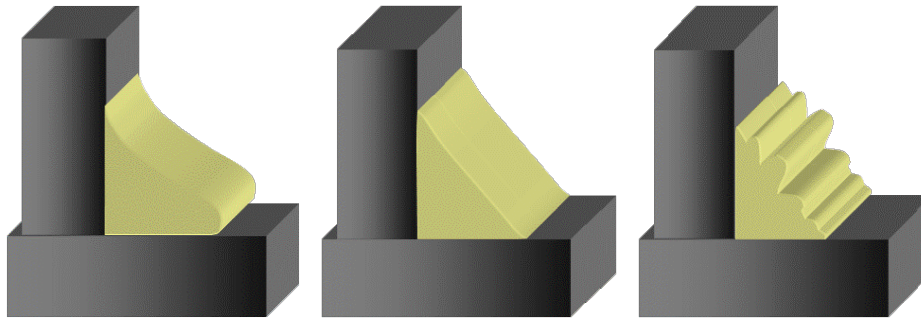


Figure 2.19 Fillet weld toe blends.

2.4 Butt welds

The design throat t_1 of a butt weld is the penetration depth below the parent plate surface and no account is made of the excess weld metal. The design throat is therefore less than the actual throat t_2 .

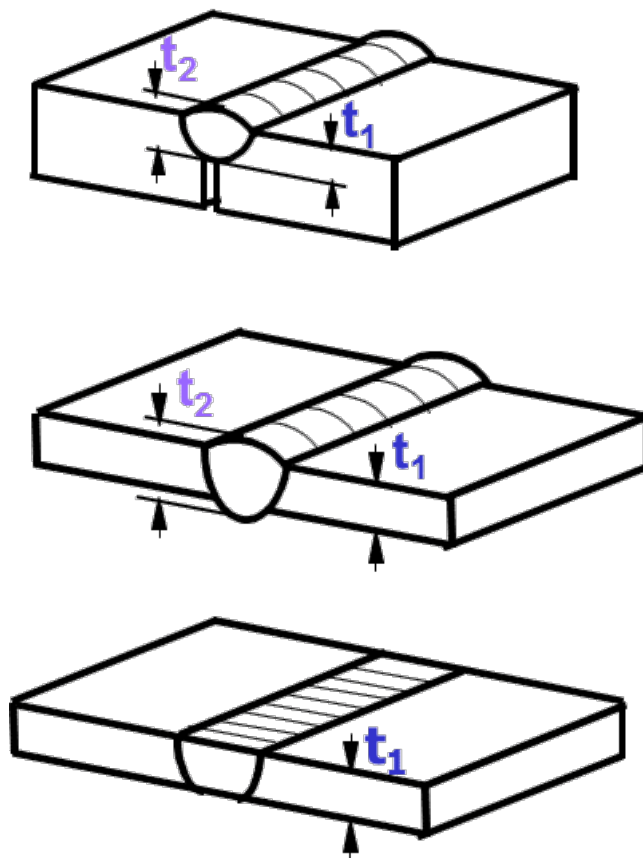
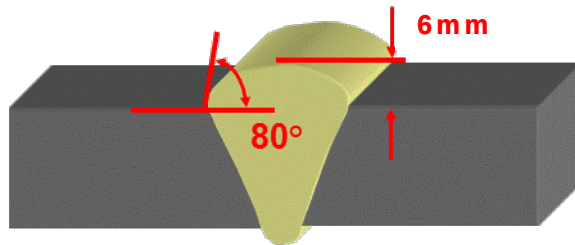
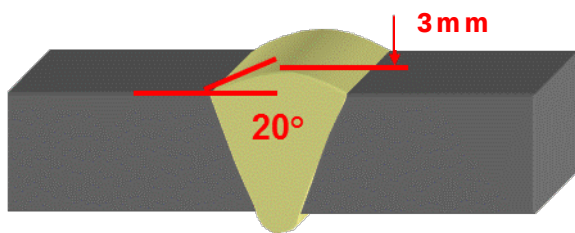


Figure 2.20 Design throat t_1 and the actual throat t_2 for butt welds.

The weld toe blend is important for butt welds as well as fillet welds. Most codes state that weld toes shall blend smoothly, leaving it open to individual interpretation. The higher the toe blend angle the greater the amount of stress concentration. The toe blend angle ideally should be between 20-30 degrees (Figure 2.21).



Poor weld toe blend angle



Improved weld toe blend angle

Figure 2.21 Toe blend in butt welds.

2.5 Dilution

When filler and parent material do **not** have the same composition the resulting composition of the weld depends largely on the weld preparation before welding. The degree of dilution results from the edge preparation and process used; the percentage of dilution (D) is particularly important when welding dissimilar materials and is expressed as the ratio between the weight of parent material melted and the total weight of fused material (multiplied by 100 to be expressed as a percentage), as shown:

$$D = \frac{\text{Weight of parent material melted}}{\text{Total weight of fused material}} \times 100$$

Low dilutions are obtained with fillet welds and with butt welds with multiple runs. For a single pass better dilution is obtained with grooved welds, see Figure 2.22.

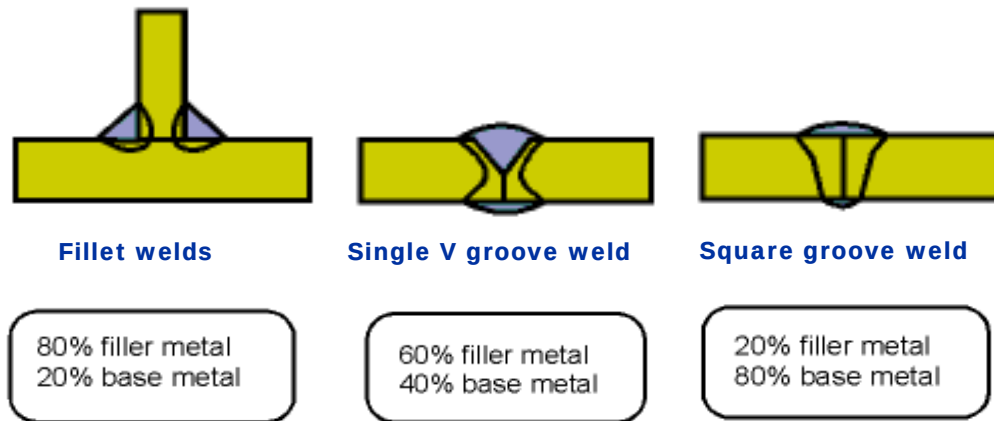


Figure 2.22 Effect of weld preparation on dilution and weld metal composition (for a single pass only).

2.6 Welding symbols

On engineering drawings a welded joint can be represented by different means. A detailed representation shows every detail and dimension of the joint preparation with carefully written, extensive notes. It provides all the details required to produce a particular weld in a very clear manner but requires a separate detailed sketch (time consuming and can overburden the drawing). For a special weld preparation not covered in the relevant standards (eg narrow groove welding); it is the only way to indicate the way components are to be prepared for welding or brazing.

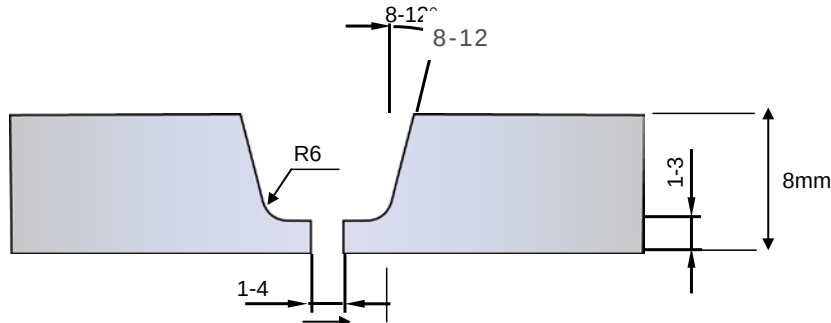


Figure 2.23 Detailed representation of U bevel angle.

Symbolic representation using weld symbols can specify joining and inspection information and the UK has traditionally used BS 499 Part 2 which has been superseded by BS EN ISO 2553. In many welding and fabrication organisations use old drawings that reference out of date standards such as BS 499 Pt 2. BS EN ISO 2553 is almost identical to the original BS EN ISO 2553 standard on which it was based. In America AWS A2.4 is followed, while symbols for brazing are given in EN 14324.

The advantages of symbolic representation are:

- Simple and quick to visualise on the drawing.
- Does not overburden the drawing.
- No need for additional views as all welding symbols can be placed on the main assembly drawing.
- Gives all necessary indications regarding the specific joint to be obtained.

Symbolic representation can only be used for common joints and requires training to understand the symbols. Symbolic representation of a welded joint contains an arrow line, a reference line and an elementary symbol. The elementary symbol can be complemented by a supplementary symbol. The arrow line can be at any angle (except 180 degrees) and can point up or down. The arrow head must touch the surfaces of the components to be joined and the location of the weld. Any intended edge preparation or weldment is not shown as an actual cross-sectional representation but as a line. The arrow also points to the component to be prepared with single prepared components.

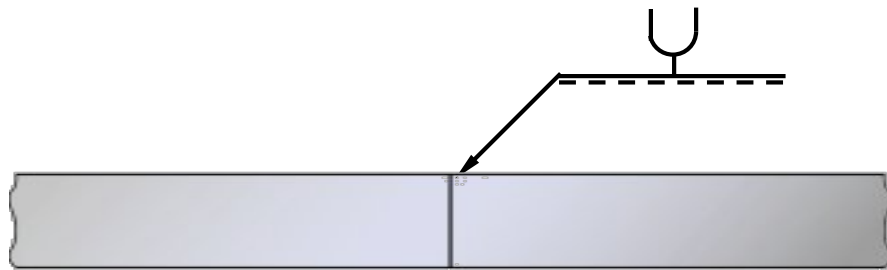
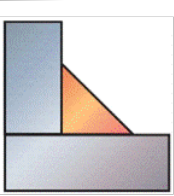
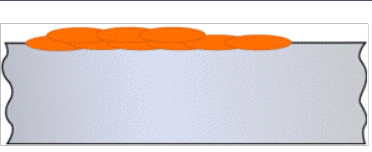
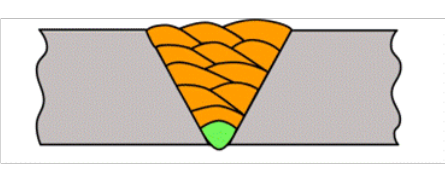
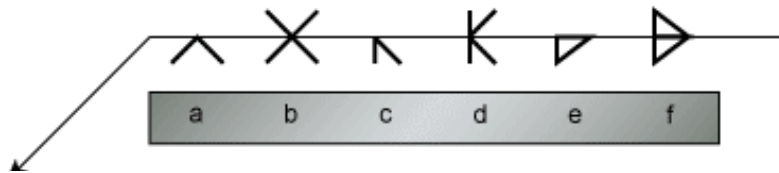


Figure 2.24 Symbolic representation of U bevel angle.

BS EN ISO 2553 and AWS A2.4 list all the main elementary symbols, some examples are shown in Table 2.1. The symbols for arc welding are often shown as cross-sectional representations of a joint design or completed weld. Simple, single edge preparations are shown in Figure 2.25.

Table 2.1 Elementary weld symbols.

Designation	Illustration of joint preparation	Symbol
Square butt weld		
Single V butt weld		∇
Single bevel butt weld		∇
Single V butt weld with broad root face (only in BS EN ISO standard!)		Y
Single bevel butt weld with broad root face (only in BS EN ISO standard!)		Y
Single U butt weld		U
Single J butt weld		J
Fillet weld		△
Surfacing (cladding)		⌒
Backing run		⌒

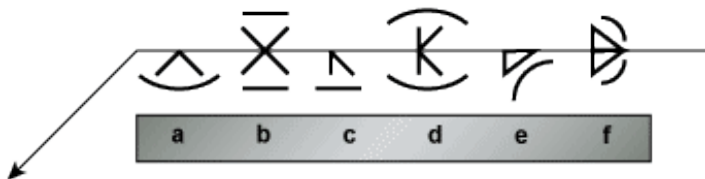


Key:

- a** = single V butt joint.
- b** = double V butt joint.
- c** = single bevel butt joint.
- d** = double bevel butt joint.
- e** = single sided fillet weld.
- f** = double sided fillet weld.

Figure 2.25 Welding symbols for the most common joint types shown on a reference line.

These simple symbols can be interpreted as either the joint details alone or the completed weld. For a finished weld it is normal for an appropriate weld shape to be specified. There are a number of options and methods to specify an appropriate weld shape or finish. Butt welded configurations would normally be shown as a convex profile (Figure 2.26 a, d and f) or as a dressed-off weld as shown in b and c. Fillet weld symbols are always shown as a mitre fillet weld and a convex or concave profile can be superimposed over the original symbol's mitre shape.



Key:

- a** = single V butt weld with convex profile.
- b** = double V butt weld flushed off both sides on weld face.
- c** = single bevel butt weld flushed off both sides on weld face.
- d** = double bevel butt convex (as welded).
- e** = concave fillet weld.
- f** = double sided convex fillet weld.

Figure 2.26 Welding symbols showing the weld profile for the most common joint types.

So the correct size of weld can be applied it is common to find numbers to the left or right of the symbol. For fillet welds numbers to the left indicate the design throat thickness, leg length or both (Figure 2.27).

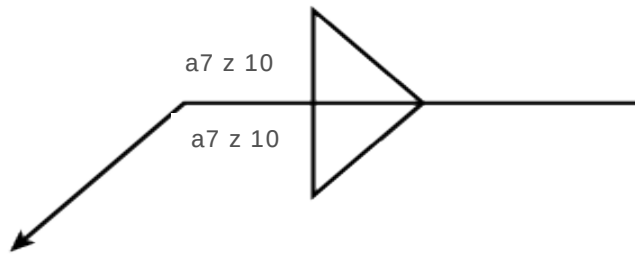


Figure 2.27 Throat and leg length dimensions given on the weld symbol for a fillet weld.

For butt joints and welds an S with a number to the left of a symbol refers to the depth of penetration. When there are no specific dimensional requirements specified for butt welds on a drawing using weld symbols, it would normally be assumed that the requirement is for a full penetration butt weld. Numbers to the right of a symbol or symbols relate to the longitudinal dimension of welds, eg for fillets the number of welds, weld length and weld spacing for non-continuous welds.

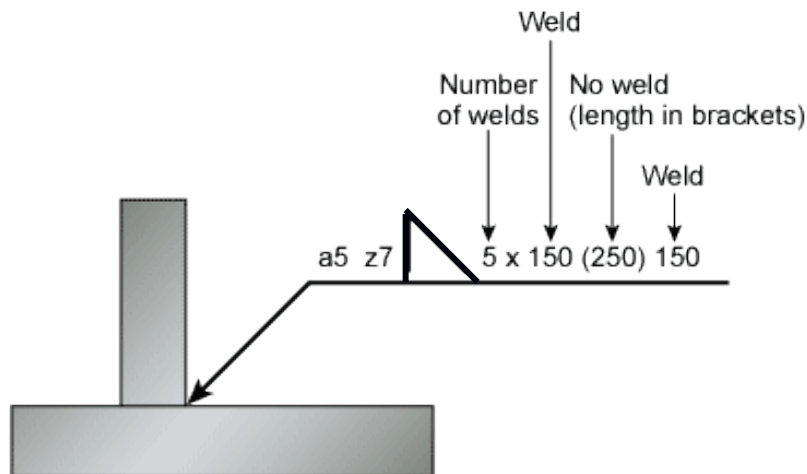


Figure 2.28 Weld symbols showing the weld length dimensions to the right of the weld joint symbols for an intermittent fillet weld.

Supplementary symbols can be used for special cases where additional information is required (Figure 2.29). The weld all round symbols may be used for a rectangular hollow section (RHS) welded to a plate, for example. The flag symbol for weld in the field or on site can be added to any standard symbol. A box attached to the tail of the arrow can contain or point to other information such as whether NDT is required. This information is sometimes the welding process type given as a three number reference from BS EN ISO 4063, for example 135 refers to MAG welding.

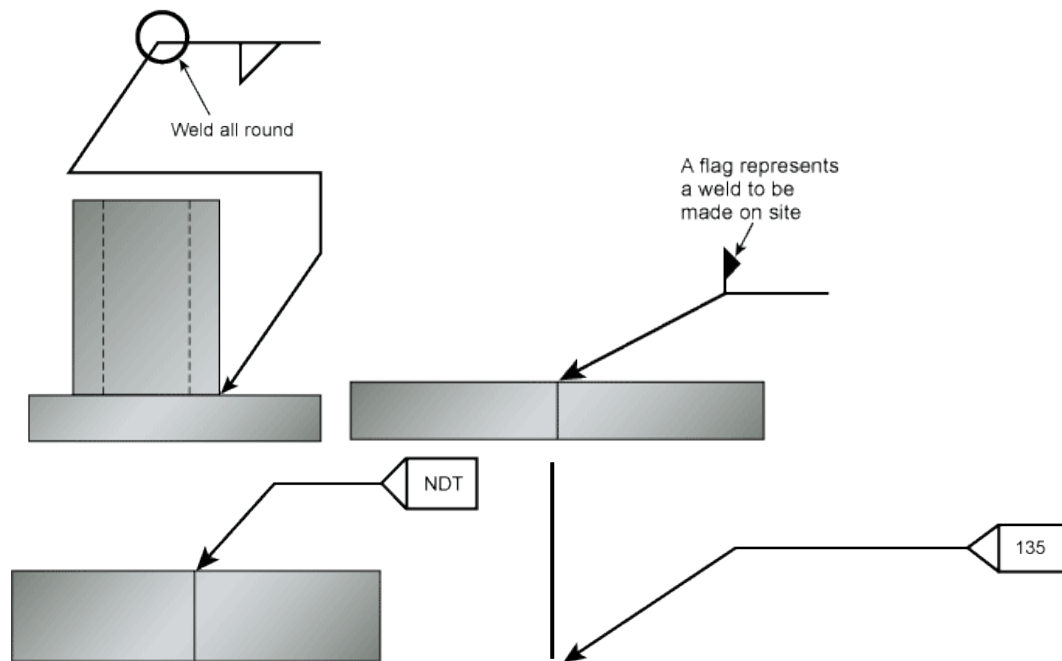
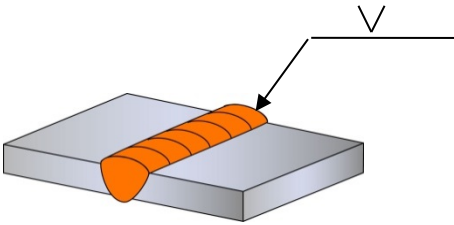
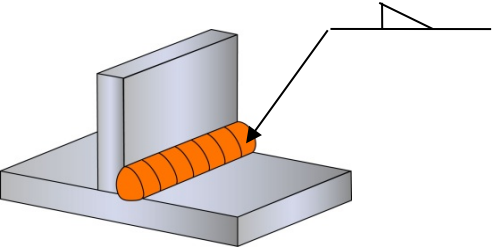
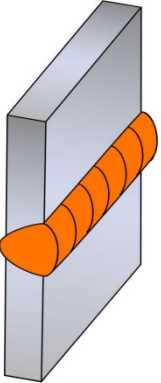


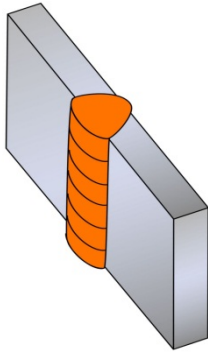
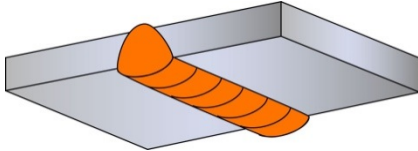
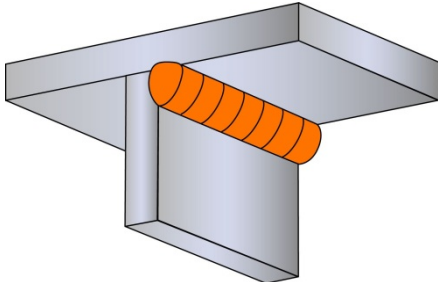
Figure 2.29 Examples of supplementary symbols.

2.7 Welding positions

In weld procedure documents and engineering drawings the type and orientation of welds are often given a two letter abbreviation which defines them which can vary depending on the standard the welds are conforming to. The abbreviations here are consistent with BS EN ISO 6947 and are summarised in Table 2.2.

Table 2.2 Welding positions.

Welding position	Figure/symbol	Abbreviation
Flat		PA
Horizontal		PB
Horizontal vertical		PC

Welding position	Figure/symbol	Abbreviation
Vertical up, vertical down		PG/PF
Overhead		PE
Horizontal overhead		PD

2.8 Weld joint preparations

The simplest weld joint preparation is a square edged butt joint, either closed or open. A closed butt joint is used in thick plate for keyhole welding processes such as laser or electron beam welding (EBW). A square edged open butt joint is used for thinner plate up to 3mm thickness for arc welding in a single pass or in thick plate for welding processes such as electroslag welding.

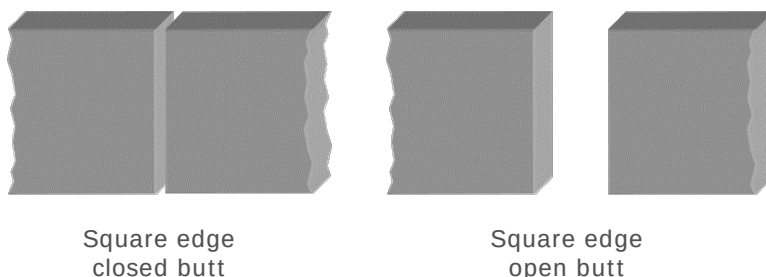


Figure 2.30 Square edge butt joints.

It is normal to use a bevel on the edges of the parent metal to be welded to allow access to the root for the first welding pass which is filled using fill passes. Single-sided preparations are normally made on thinner materials or when access from both sides is restricted. Double-sided preparations are normally made on thicker materials or when access from both sides is unrestricted.

Edge preparation design includes the bevel angle (or included angle if both sides are bevelled) and also the square edges root face and root gap. In a joint where both sides are bevelled the preparation is termed a V or vee preparation (Figure 2.31). V preparations are usually used for plate of 3-20mm thickness. An alternative is a U preparation (or J preparation if only one side has the edge preparation) where the edge is machined into the shape of a U. This is used in thicker plate, over 20mm thickness, where it uses less filler metal than a V preparation joint. J or U edge preparations also require a bevel angle and root face, the gap to be defined, a root radius and land to be specified (Figure 2.32). Single-sided edge preparations are often used for thinner materials or when there is no access to the root of the weld (pipelines). If there is access to both sides of the material then a double-sided edge preparation is used, especially for thicker materials. Single and double edge preparations are shown in Figure 2.33.

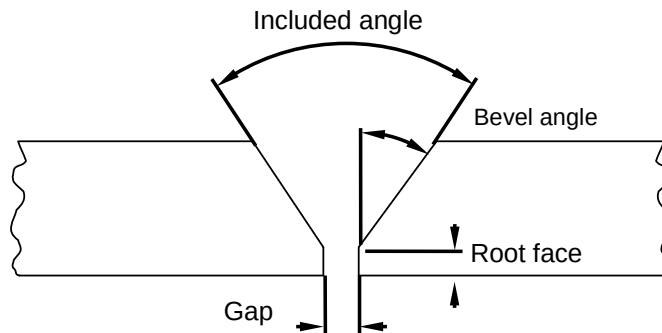


Figure 2.31 Single V bevel.

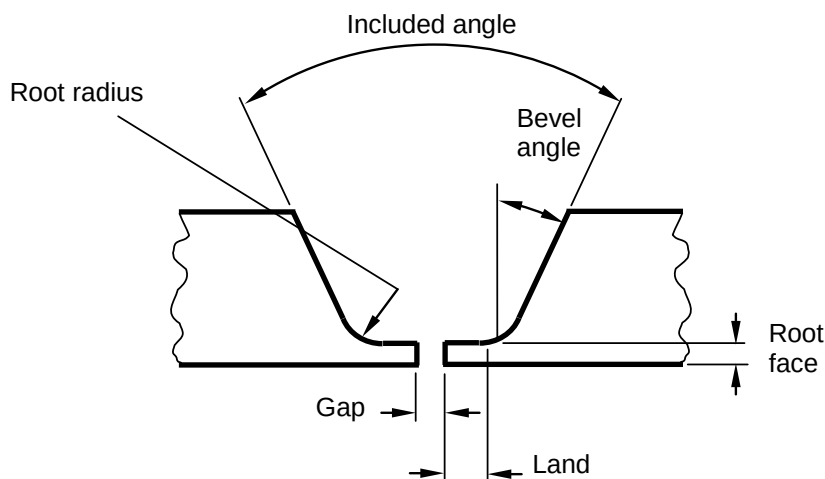


Figure 2.32 U bevel.

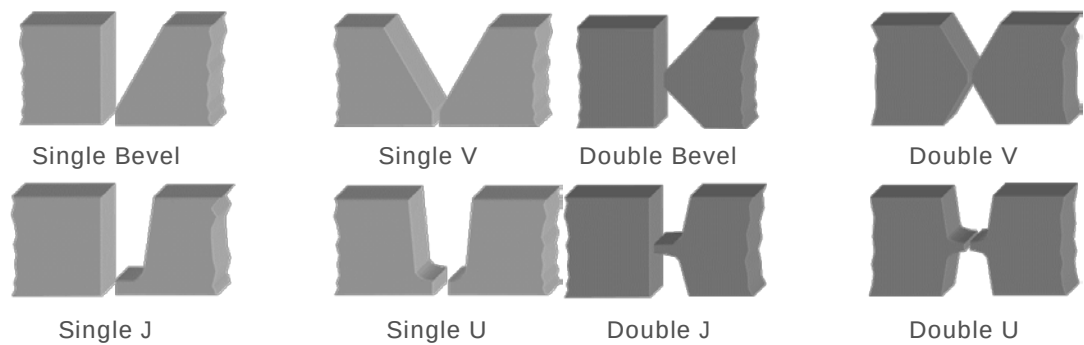


Figure 2.33 Range of single and double-sided bevel, V, J and U preparations.

2.9 Designing welded joints

Weld joint design selection will also be influenced by practical issues such as the welding process used and the access required to obtain root fusion. The bevel angle must allow good access to the root and sufficient manipulation of the electrode to ensure good sidewall fusion (Figure 2.34). If the included angle is too large then heavy distortions can result and more filler metal is required. If the included angle is too small there is a risk of lack of penetration or lack of sidewall fusion. Typical bevel angles are 30-35 degrees in a V preparation (60-70 degrees included angle). In a single bevel joint the bevel angle might be increased to 45 degrees.

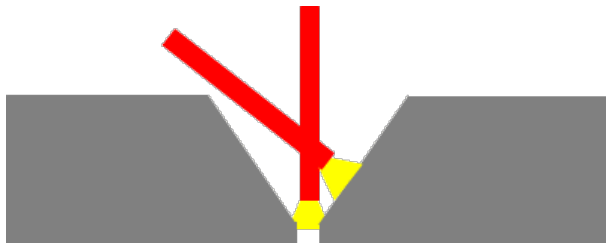


Figure 2.34 Bevel angle to allow electrode manipulation for sidewall fusion.

The root gap and face are selected to ensure good root fusion (Figure 2.35). This will depend on the welding process and heat input. If the root gap is too wide or root face too narrow there is a risk of burn through. If the root gap is too narrow or root face is too deep there is a risk of lack of root penetration. A balance must be found and designed for; this difference in weld root size is shown in Figure 2.36. High heat input processes require a larger root face but less weld metal which reduces distortions and increases productivity. Typical values for the root face are 1.5-2.5mm and the root gap 2-4mm.

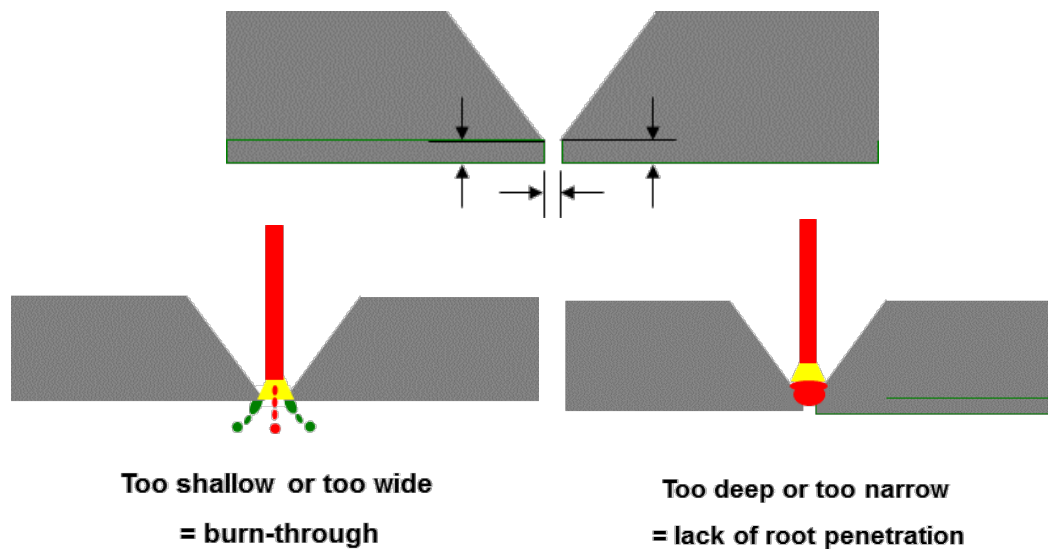


Figure 2.35 The importance of selecting the correct root face and gap.

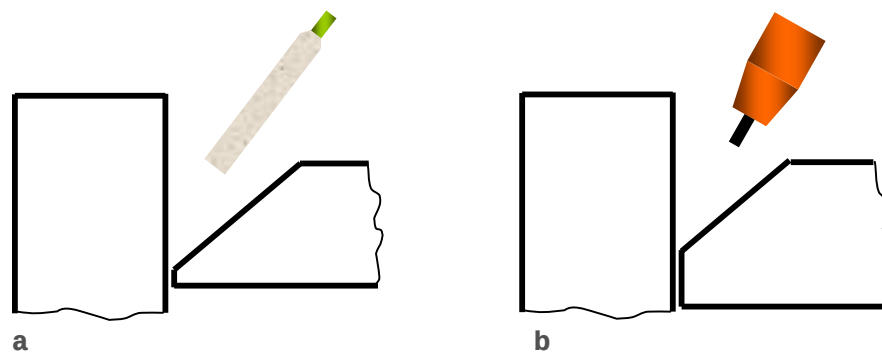


Figure 2.36 Root size for welding processes with different heat inputs:

a Low heat input.

b High heat input.

If the components are to be joined by an arc welding process the selected bevels need to be adequately machined to allow the welding tool to access the root of the weld. This consideration would not apply for a procedure such as EBW as shown in Figure 2.37. If using gas-shielded processes then the size of the gas nozzle may limit the ability to use a J preparation for thick section material as it would be difficult to ensure good root fusion if the welding head could not access the bottom of the weld groove and a single bevel may be needed instead (Figure 2.38).

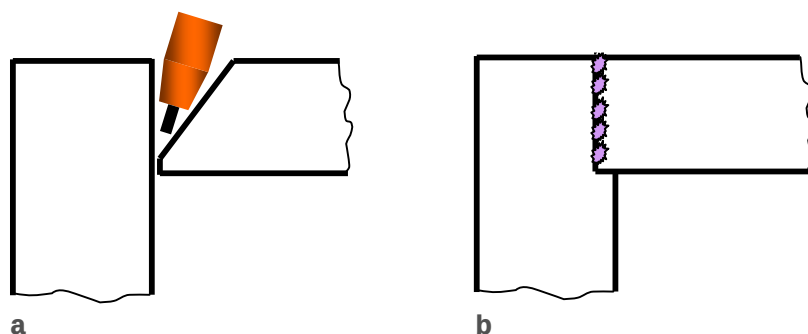


Figure 2.37 Preparation differences between:

- a Arc.**
- b Electron beam welding.**

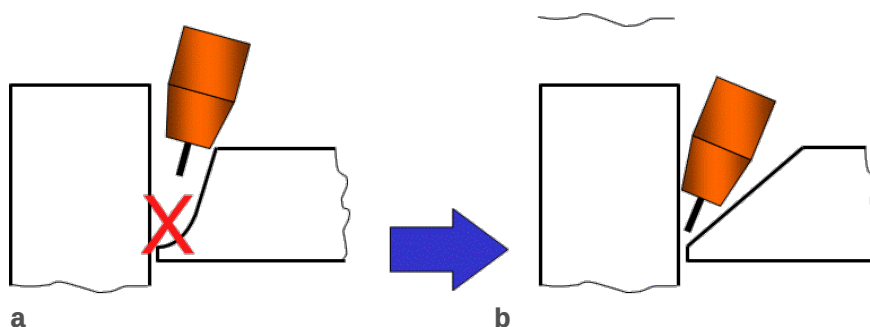


Figure 2.38 Using gas-shielded arc welding:

- a Difficulties of root access in a J preparation.**
- b Improved design using a bevel preparation.**

Choosing between a J or U preparation and a bevel or V preparation is also determined by the costs of producing the edge preparation. Machining a J or U preparation can be slow and expensive. Using this joint design also results in tighter tolerance which can be easier to set-up. A bevel or V preparation can be flame or plasma cut fast and cheaply resulting in larger tolerances, meaning that set-up can be more difficult.

Backing bar or strip is used to ensure consistent root fusion and avoid burn through. Permanent backing bar (rather than one removed after welding), gives a built-in crevice which can make the joints susceptible to corrosion (Figure 2.39). When using backing for aluminium welds any chemical cleaning reagents must be removed before assembling the joint. A backing bar also gives a lower fatigue life.

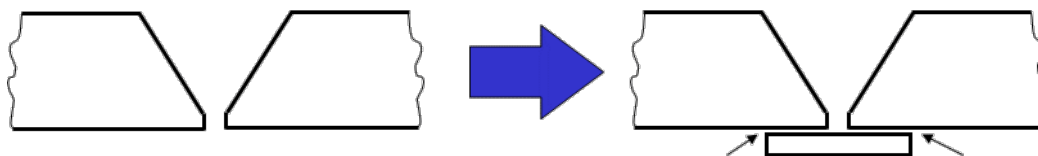


Figure 2.39 Using a backing bar for a butt weld.

Separate from the design of the joint and weld access to weld locations and the order in which welds are made are important. Figure 2.40 shows examples of the limitations of access in designing welded joints and gives improved designs. It is important to ensure that it is indeed possible to make welds as required by the drawing.

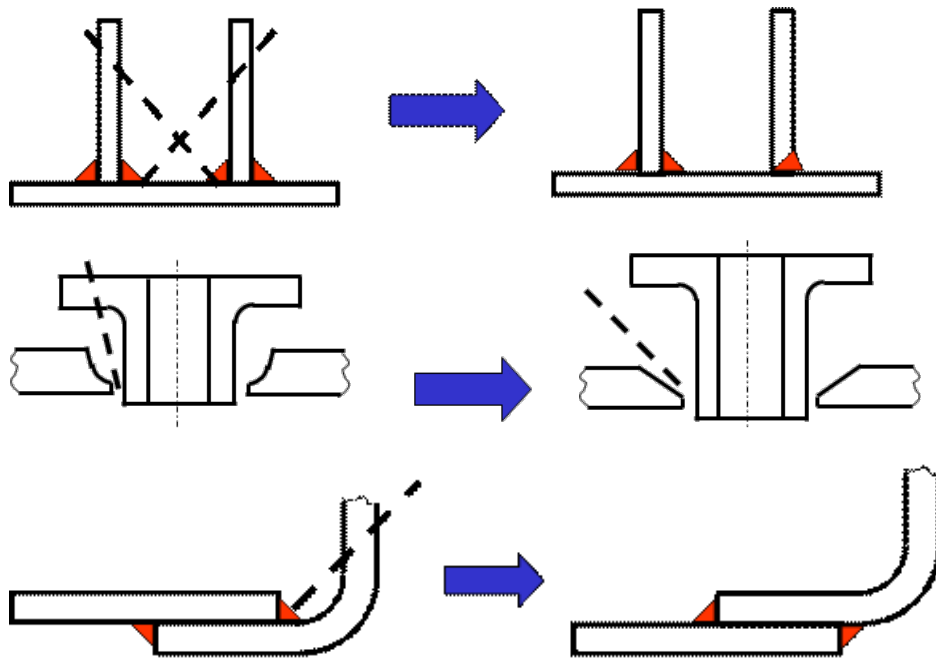


Figure 2.40 Examples of improved weld designs where there is limited access.

2.10 Summary

You should now:

- Be able to label the parts of a butt and fillet weld and of a V and U edge preparations.
- Recognise welding symbols and know what they mean.

TWI

Welded Joint Design

Section 2

Materials Joining and Engineering Technologies
Training and Examination Services

TWI

Outline

- What determines joint Design?
- Weld features.
- Types of welded joints.
- Welding symbols.
- Weld positions.
- Weld bevels.
- Designing welded joints.

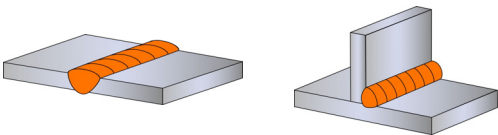
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Types of Welds

Weld
A permanent union between materials caused by heat, and or pressure (BS499).

Butt weld **Fillet weld**

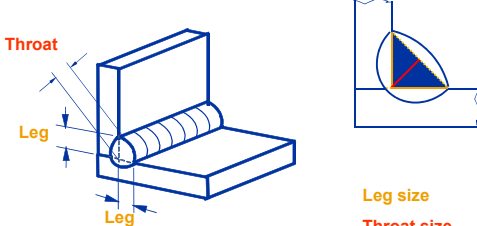


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Fillet Welds

Fillet welds



Throat

Leg

Leg size

Throat size

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Butt Joint Preparations



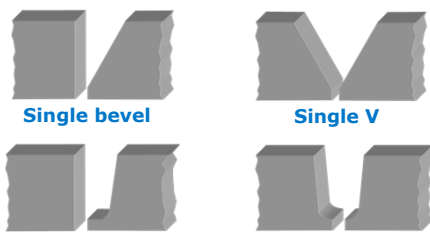
Square Edge Closed Butt **Square Edge Open Butt**

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Single Sided Butt Preparations

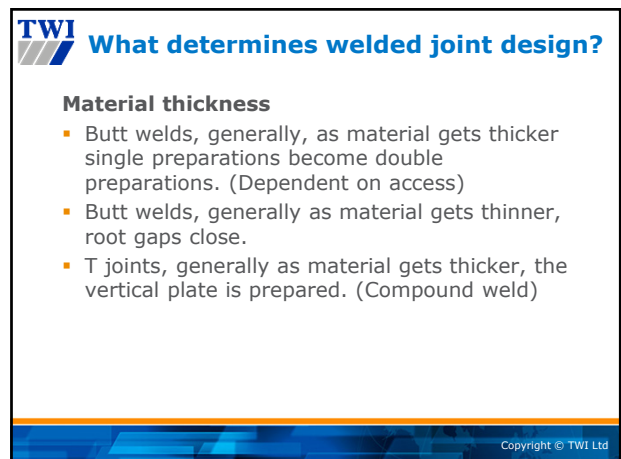
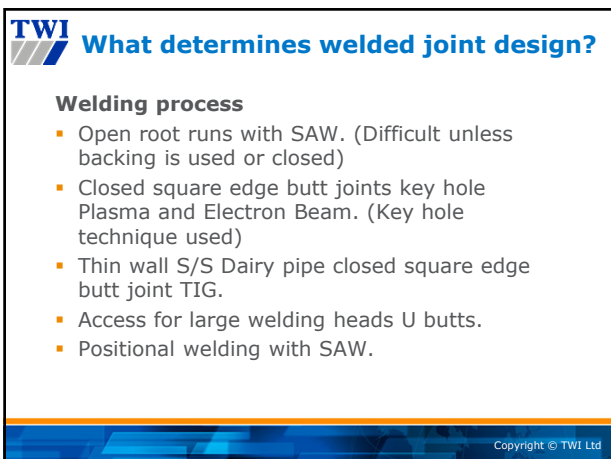
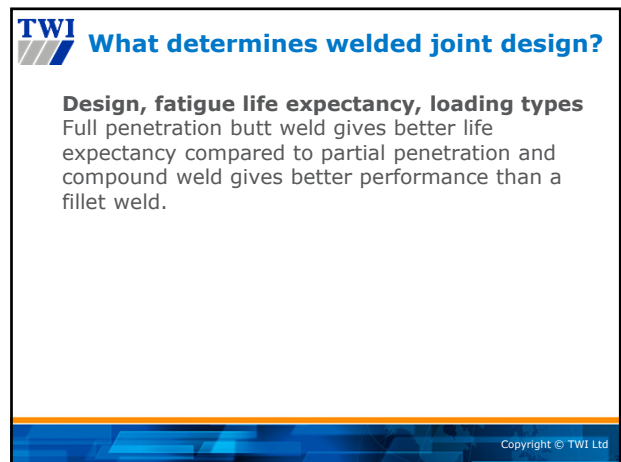
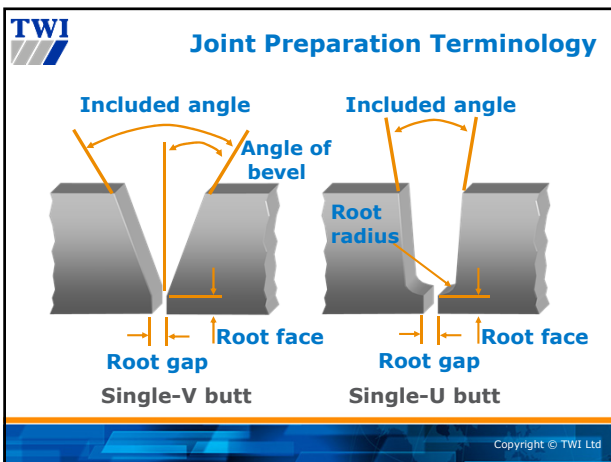
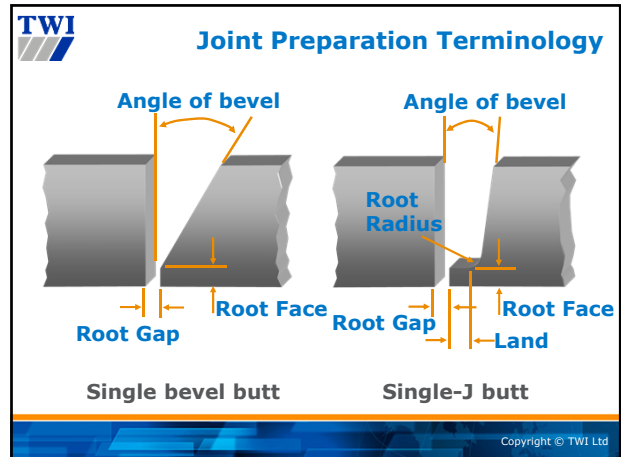
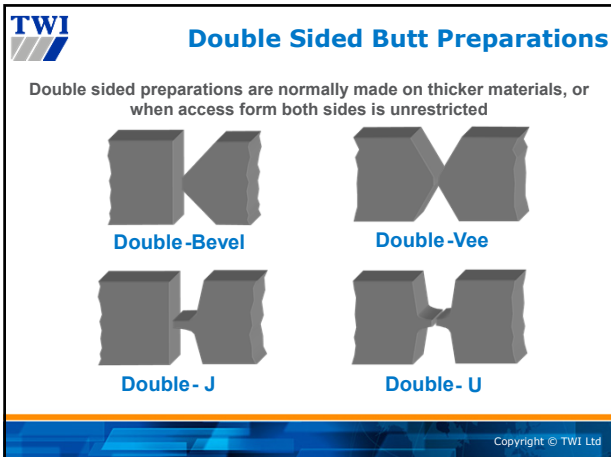
Single sided preparations are normally made on thinner materials, or when access from both sides is restricted



Single bevel **Single V**

Single-J **Single-U**

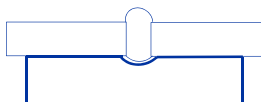
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TWI What determines welded joint design?

Quality

Root penetration is guaranteed if backing is used, ceramic or a material that won't fuse, shaped to produce a particular profile.

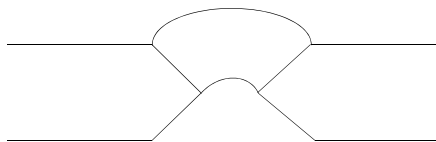


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TWI What determines welded joint design?

Quality

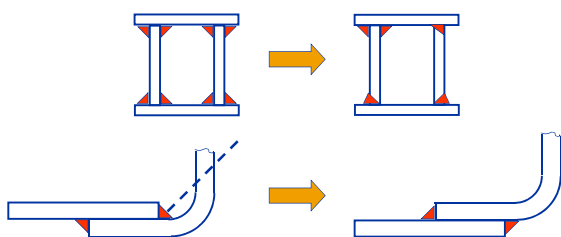
To ensure that root defects are minimised, back gouge and check via NDT, MPI/Dye pen.



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TWI Access and Weld preparations

Access impacts upon weld preparation



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TWI What determines welded joint design?

Welding position



Preparation for horizontal welding using the submerged Arc welding process

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TWI What determines welded joint design?

Welding position



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TWI What determines welded joint design?

Weld volume



- A U butt between 20-30% less weld volume than a V Butt.
- The benefits could be reduced costs, reduced residual stress and reduced distortion.
- The disadvantages of the U is the additional preparation costs of machining although fit up conditions improve.

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TWI What determines welded joint design?

Weld volume



- A double V has less weld volume than a single V.
- A double V, therefore will reduce cost, reduce distortion and stress and should guarantee higher quality.
- Disadvantage of the double V, access to both sides required.

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TWI What determines welded joint design?

Distortion control

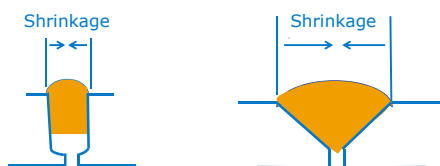


- The asymmetrical V butt, $\frac{1}{3}, \frac{2}{3}$ is often used to control distortion. The smaller v is completed first.

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TWI What determines welded joint design?

Distortion control

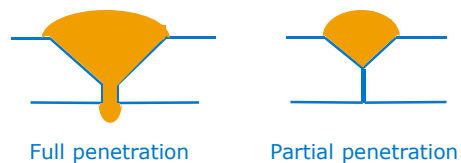


The U butt has significantly less liquid metal and a more even distribution of weld metal in the upper most regions than the V butt. Therefore, greater shrinkage and distortion occurs with the V butt.

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TWI What determines welded joint design?

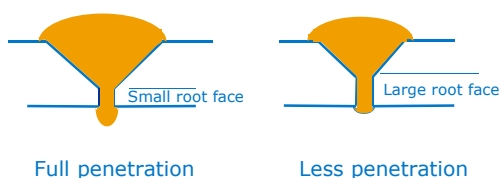
Level of penetration



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TWI What determines welded joint design?

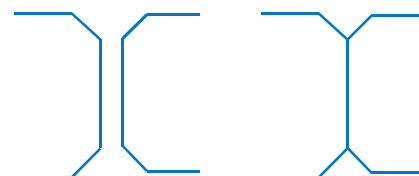
Level of penetration



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TWI What determines welded joint design?

Gas purging of pipes



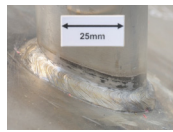
It is much easier to regulate the gas purge if the joint is closed.

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Nozzles

Nozzles connect a pressure vessel with other components



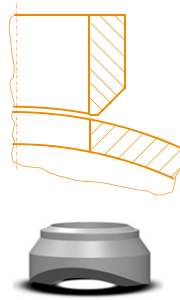
Type of nozzle depends on

- Diameter/thickness ratio of the shell.
- Diameter/thickness ratio of the nozzle.
- Access (one side only or both sides).
- Type of joint required (partial/full pen).
- Groove preparation methods available.

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Set-On Nozzle

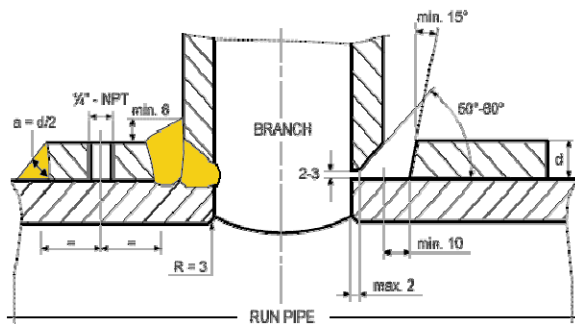


- Shorter nozzle is cheaper.
- Easy to make groove for full or partial penetration.
- Single side welding in 2G/PB position means high welder skill is required.
- Through thickness stress means danger of lamellar tearing.
- Can be difficult to UT especially on smaller diameters.
- Mainly used for small (<2inch diameter) nozzles, or thick wall or large diameter vessels.
- May require reinforcement.
- Extra cost to shape nozzle to radius of shell.

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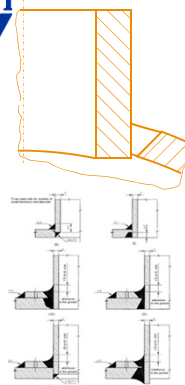
Set-On Nozzle



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Set-Through Nozzle



- 1G/PA position much easier.
- Groove prep can be flame cut.
- No danger of lamellar tearing.
- Easy access to the back side of root, so full penetration is easier to achieve.
- For nozzles with small diameters no need for reinforcement.
- Nozzle body needs to be longer.
- Greater weld volume means higher distortions.
- Can be hard to UT on smaller diameters, usually easy to inspect.
- Used for larger diameter nozzles, and thinner walled small diameter vessels.

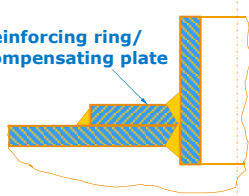
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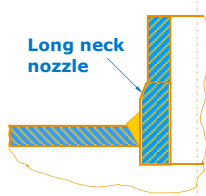
Reinforcement or Compensation

To compensate for loss in strength, we can reinforce either the shell or nozzle

Reinforcing ring/
Compensating plate



Long neck
nozzle

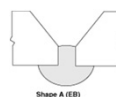


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What determines welded joint design?

Less known joint designs

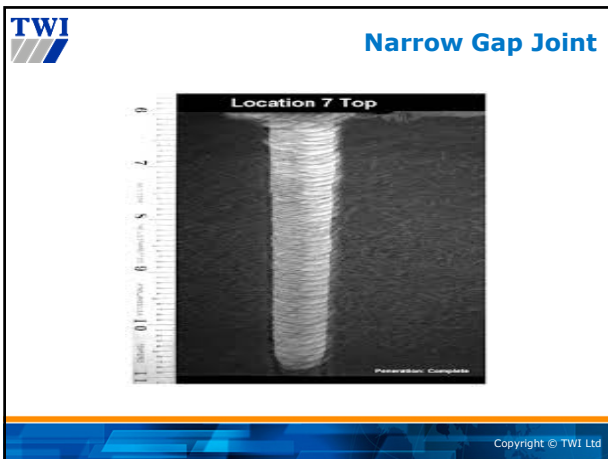


Welded insert, consumable socket ring (CSR) or EB insert, used on small bore pipework where consistent root penetration is required.



Sweepolet, shaped to fit radius of shell, butt welded to shell with a butt joint on the vertical stem.

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Joint Design

As a Senior Welding Inspector you are assigned to the fabrication of a C/Mn pressure vessel.

The vessels main barrel thickness and dished ends are 25mm wall thickness, all nozzles (set in and set on), man ways 20mm thickness.

During the fabrication and welding your main concerns are distortion control, joint design, and all other quality aspects.

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Question 1

You notice that the joint preparations are not shown on the Engineering drawing for a set in nozzle attachment. Which of the following preparations would be suitable when a full penetration weld was required?

- a. Single bevel butt joint
- b. Fillet joint
- c. Lap joint
- d. Corner weld

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Question 2

You notice that the joint preparations are not shown on the Engineering drawing or the WPS. In the case of a set on nozzle attachment which of the following joint preparations would be the most suited?

- a. Open corner joint
- b. Fillet joint
- c. Single bevel butt joint
- d. Single V butt joint

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Questions 3

The fabricator suggests to you that it would be much more cost effective to weld up the pressure vessel from the out side only without any back gouging. The WPS shows all the main barrel sections and dished end to barrel joints are full penetration butt welds, welded by the SAW welding process, back gouged root from the inside, welded with the MMA process. Would you agree with his suggestions?

- a. Yes, SAW welding can be used from one side providing the root gap is greater than 3mm
- b. Yes, SAW welding can be used from one side and would provide a much stronger joint when compared to a back gouged joint
- c. No, SAW welding would never be considered on any material <50mm thickness
- d. No, the SAW welding process can't be used on a open root joint welded from one side only

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Question 4

When considering distortion, which of the following butt weld preparations would be the most suited for the longitudinal welded main barrel joints?

- a. Double U butt weld
- b. Single V butt weld
- c. Single U butt weld
- d. All options would produce the same amount of distortion

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Question 5

The fabricator proposes to you that he wishes to reduce the bevel angle from 45° to 30° on the set on nozzle joints. Which of the following issues may occur if this was permitted?

- a. The reduction in bevel angle may result in an increase in distortion
- b. The reduction in bevel angle may result in a greater risk of lack of fusion and would not be compliant with the specification
- c. The reduction in bevel angle would result in requalification of all the welders
- d. All options may apply

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Question 6

Which distortion control technique is referenced in the TWI specification?

- a. Raised heat input technique
- b. Back welds
- c. Back skip welding
- d. Full penetration welds

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Question 7

In accordance with the TWI Specification would it be permissible to hard stamp the vessel's material for the purpose of material identification?

- a. Yes, any hard stamping is permitted providing the information is on both ends of the material
- b. No, hard stamping isn't allowed in any situation
- c. Yes, hard stamping is permitted providing a low stress concentration die is used.
- d. No options are correct

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Question 8

During fit-up you notice that the longitudinal seams have two different bevel angles on one joint, top bevel 50°, bottom bevel 15°. Is this permitted in accordance with TWI Specification?

- a. No, under no situation shall different bevel angles be permitted on a single V joint
- b. Yes, providing the joint is welded either in the overhead or vertical horizontal positions
- c. No, the bevel angles stated are out of specification
- d. Yes, As long as there is access this would be acceptable

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Question 9

While inspecting the completed vessel, you notice that some of the longitudinal seams on the main barrel section are in line with each other, ie not offset:

- a. This would be permitted providing the linear misalignment doesn't exceed 1.5mm
- b. This is not permitted all longitudinal seams shall be off set to each other by 90°
- c. The TWI Specification makes no mention of this requirement
- d. This would be permitted providing the angular misalignment doesn't exceed 3°

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Question 10

The fabricator wishes to reduce welding time and distortion on the longitudinal and circumferential welds, which of the following will best achieve this?

- a. Single V butt joints, welded by the MMA process
- b. Double V butt joints, welded by the SAW process
- c. Double U butt joints, welded by the SAW process
- d. Heterogeneous welds

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Section 3

Quality Assurance and Quality Control

3 Quality Assurance and Quality Control

3.1 Definitions

Before we consider what quality assurance and quality control are, let us first define quality. This is best described as the fitness-for-purpose of a product, service or activity.

Quality assurance comprises all the planned and systematic actions necessary **to provide adequate confidence** that a product or service will satisfy given requirements for quality. Quality control is described as the **operational techniques** and activities that are used to fulfil requirements for quality.

Quality assurance therefore encompasses the plans and systems by which confidence in a product is provided, ie all of the paperwork used to plan, control and record activities: the documentation.

Quality control describes the activities which monitor the quality of the product. These operational techniques include materials and dimensional checks, inspection before, during and after welding, non-destructive testing, hydraulic or leak testing, ie activities which check **after** the event that a specified activity has been carried out correctly.

Quality assurance has been introduced to ensure that the activity 'gets it right the first time', based on the principle that prevention is better than cure. This can be achieved by planning and anticipating problems.

In order to satisfy this requirement, a documented quality system is needed which sets out in a formal framework the basis of control for the critical activities. This framework generally comprises four tiers of documentation, the highest tier being the company quality manual, followed by quality systems, quality plans and detailed manufacturing and inspection instructions.

3.1.1 Quality system

A quality system can be defined as:

The organisation structures, responsibilities, procedures, processes and resources for implementing quality management.

The quality manual and support procedures document an organisation's quality system.

3.1.2 Quality manual

A quality manual can be defined as:

A document setting out the general quality policies, procedures and practices of an organisation.

The word 'general' is important in this definition. The quality manual is usually the first indication a purchaser or prospective client has of a company's approach to quality. This document should contain a statement of the company's total commitment to quality by means of a quality policy statement signed by the Chairman, MD or Chief Executive of the company. This policy statement should be prominently displayed within the company.

3.1.3 Procedure

A procedure can be defined as:

A document that describes how an activity is to be performed and by whom.

Note: A procedure is not a detailed work instruction such as a welding procedure, but rather a statement of who does what and how: it describes the corporate plan for achieving quality. However, there may be times when an organisation needs to operate in a different way from the corporate system, for example for a unique project or to satisfy a specific customer's requirements.

In these circumstances, an appropriate quality system can be documented in the form of a project off-contract specific quality plan.

3.1.4 Quality plan

A quality plan can be defined as:

A document setting out the specific quality practices, resources and sequence of activities relevant to a particular product, service, contract or project.

A quality plan is the corporate quality system suitably modified to reflect specific equipments. It may comprise a project quality manual incorporating appropriate sections from the corporate quality manual which apply. It is generally a detailed document.

Project procedures may include:

- Existing procedures appropriate to the contract.
- Existing procedures amended for the contract.
- New procedures to meet new specific requirements of the contract.

Some contracts may well call for a combination of all three.

3.2 Quality system standards

Quality system standards specify the minimum requirements of quality systems for application to specific products or services.

Standards are normally used for the following purposes:

- As guidance to an organisation introducing quality assurance.
- As a basis for evaluating an organisation's quality system (assessment).
- To specify the quality assurance requirements when invoked in a contract.

The most common standard in the UK is ISO 9000.

3.2.1 Quality records

A quality record is any document that specifies the inspection performed, quantities inspected, results obtained, positive identification of the material inspected to drawing or part number, the signature or stamp of the person carrying out the inspection and date of inspection. Quality records may also indicate the qualifications of personnel, calibration of equipment or other records not directly related to the product.

Questions that need to be addressed include:

- What quality records are to be maintained, eg received inspection reports, NDT results, test certificates, final inspection reports and non-conformance reports (including any feedback or corrective action generated)?
- Where are the records filed and by whom?
- How long are the quality records retained?
- Are the quality records available to the customer for analysis and review?
- Are records easily retrievable?
- Is a suitable environment available to minimise deterioration or damage to stored records?

3.2.2 Typical quality record contents

The Quality Record Package for a welded product is defined specifically for each contract, but should include the following types of information:

- a Records of stage inspections in the form of check sheets or quality plans.
- b Non-conformity reports and concession records.
- c Where appropriate, as-built drawings.
- d Welding procedures.
- e Welder approvals.
- f Welding consumable records.
- g Weld history records.
- h NDT reports.
- i Heat treatment records.
- j Hydraulic and/or other testing records.
- k Where appropriate, material test certificates.
- l Final acceptance certificates.

3.2.3 What areas of a business need to be covered by ISO 9001?

ISO 9001 requires the following elements of a business to have set procedures:

- Management responsibility - who is responsible for what?
- Quality system - how does the system operate?
- Contract review - allows personnel to see what the requirement is and who has been asked to do what.
- Design review and control - ensures smooth passage from drawing board to end product.
- Documentation controls - make sure the correct documents are available.
- Purchasing - make sure the right products and services are available.
- Purchaser supplied product - make sure that purchased items are in a satisfactory condition.
- Product identification and traceability - what is it and where is it?
- Process control - lets everyone know clearly how to make the product.
- Inspection and test - describes how to inspect and test the product.
- Inspection, measuring and test equipment - make sure the equipment used is correct.
- Inspection and test status - where is the product in the inspection cycle?
- Control of non-conforming product - ensures incorrect product is not used.
- Corrective action - finds the root cause of the problem and solves it.
- Handling, storage, packing and delivery - don't damage it now it's made.
- Quality records - fulfils the need for documented evidence that the company meets specific requirements.
- Internal quality audits - are quality activities performed as planned?
- Training - the product cannot be manufactured effectively if people are not adequately trained and qualified.
- Servicing - if carried out by the company, effective procedures are required.
- Statistical techniques - used to build-in product quality.

3.3 Auditing and documentation

Quality manuals, procedures, work instructions etc provide objective evidence that the systems of control have been adequately planned.

The records and documentation generated by carrying out work in accordance with these systems provide the evidence that the systems are being followed by all. Systems of control, no matter how effective they are, will tend to deteriorate because of human errors being made or perpetuated or due to changes in the nature of the business.

In order to ensure that the systems are effective and being followed, as well as to determine if changes are needed, it is necessary to monitor the systems. This is achieved by auditing them and reviewing the results of the audit in order to implement any changes.

3.3.1 What is an audit?

Quality audits examine a quality system for adequacy and correct implementation.

They are defined in BS 4778 Part 1 as:

Systematic and independent examinations to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives.

Auditing is carried out to provide objective evidence that the system is working in accordance with the procedures. When an audit is complete the results are analysed by management who must ensure that the quality policy is satisfied and modify the quality system if necessary.

3.3.2 Which type of audit?

There are two levels of audit:

- A systems audit, which is quite superficial and simply examines the system to confirm that it follows the quality manual and that procedures are in place.
- A compliance audit, which is an in-depth audit examining compliance with procedures.

3.3.3 Auditing of documentation

A documentation audit is regarded as being a compliance audit, where documentation is examined in depth.

Items to check in such an audit should include:

- Is all the documentation available?
- Is the documentation schedule in accordance with contract or specification requirements?
- Does the documentation itself comply with contract or specification requirements? For example, are the weld procedure and welders correctly qualified?
- Is the material composition correct?
- Is the documentation legible?
- Have all the interested parties, eg inspection department, independent third party inspectors and client inspectors, signed off where required?
- Have provisions been made for storage (which includes the ability to retrieve documents and storage conditions preventing deterioration)?

Documentation audits should be carried out by the manufacturer/supplier as a matter of course.

Customers will also frequently require access to carry out their own audits. Remember that no job is finished until the paperwork is complete.

Failure of a documentation audit carried out by a client will often result in a delay in payment, even though the component may have been delivered to the client. There can often be a consequential financial penalty.

3.4 Quality requirements for welding

Within the international community, welding has been defined as a special process which means that it must be controlled by specialist management and utilise specialist personnel.

The welding co-ordination BS EN ISO 14731 and welding quality systems standards BS EN ISO 3834 have been prepared in support of this ruling.

It is perceived that these standards will serve as references for other application standards and be used as set criteria for the qualification of fabricators.

Currently there are a number of European Standards or codes that refer to BS EN ISO 3834:

- EN 13445:2002: Unfired pressure vessels.
- prEN 15085: Railway applications – Welding of railway vehicles and components.
- prEN 1090: Execution of steel structures.
- EN 12732: 2000 Gas supply systems – Welding steel pipework – functional requirements.
- EN 12592: 2001 Water tube boilers and auxiliary installations.
- National Structural Steelwork Specification for Building Construction (5th Edition) (NSSSBC).

It is an increasingly common requirement for the fabricator to have a quality system compliant with ISO 3834. This is to be specified as a condition of the customer contract.

3.4.1 Qualification of welding fabricators – BS EN ISO 3834

BS EN ISO 3834 comprises five parts:

Part 1 - Guidance for use

This describes how the standard works.

Part 2 - Quality requirements for welding - Fusion welding of metallic materials - Comprehensive quality system

This standard is suitable for use by a manufacturer or an assessment body, as a supplement to ISO 9001 or 9002 providing detailed guidance on the requirements that must be in place to adequately control welding.

Part 3 - Quality requirements for welding, Fusion welding of metallic materials - Standard quality system

This standard can be applied where a documented quality system for the control of welding is required but will not be used in conjunction with ISO 9001 or 9002.

Part 4 - Quality requirements for welding - Fusion welding of metallic materials - Elementary system

This standard provides criteria appropriate for the control of welding when either of the following applies:

- A quality system according to ISO 9001 is not to be applied.
- The combination of selected welding processes, procedures and the final welds are such that documented welding controls have minor importance in respect to the overall integrity of the product.

Part 5 - Documents with which it is necessary to conform to claim conformity to the quality requirements of BS EN ISO 3834-2, BS EN ISO 3834-3 or BS EN ISO 3834-4

This lists all other documents or standards that are required for compliance with BS EN ISO 3834, such as specification and qualification of welding procedures, approval testing of welders, etc.

The manufacturer should select one of the three parts (2-4) specifying the different levels of quality requirements, based on the following criteria:

- The extent and significance of safety-critical products;
- The complexity of manufacture;
- The range of products manufactured;
- The range of different materials used;
- The extent to which metallurgical problems may occur;
- The extent to which manufacturing imperfections, eg misalignment, distortion or weld imperfection, affect product performance.

This approach offers a cascading qualification; for example, Part 2 (comprehensive) also gives compliance for lower levels.

As previously stated, BS EN ISO 3834 is intended to complement, rather than conflict with, quality systems established to meet the requirements of ISO 9001 and, in the case of a comprehensive quality system for welding fabrication (Part 2), requires in addition to ISO 9001 that specific procedures are used to control the following:

- 1 Review of requirements.
- 2 Technical review.
- 3 Sub-contracting.
- 4 Welders and welding operators.
- 5 Welding co-ordination personnel.
- 6 Inspection and testing personnel.
- 7 Production and testing equipment.
- 8 Equipment maintenance.
- 9 Description of equipment.
- 10 Production planning.
- 11 Welding procedure specifications.
- 12 Qualification of welding procedures.
- 13 Batch testing of consumables (if required by contract).
- 14 Storage and handling of welding consumables.
- 15 Storage of parent material.
- 16 Post-weld heat treatment procedure.
- 17 Inspection and testing before, during and after welding.
- 18 Non-conformance and corrective actions.
- 19 Calibration or validation of measuring, inspection and testing equipment.
- 20 Identification during process (if required by contract).
- 21 Traceability (if required by contract).
- 22 Quality records (if required by contract).

A company applying for certification to ISO 3834 will usually be required to complete the following stages:

- Client returns preliminary enquiry.
- Quotation.
- Detailed forms sent to client.
- Assessment team appointed by auditor.
- Preliminary visit by auditor (not mandatory but common) to carry out a gap analysis.
- Document review by auditor to review procedures against BS EN ISO 3834.
- On-site assessment conducted by auditor to demonstrate that the client has accrued evidence that procedures are used and that these are overseen by the welding co-ordination team.
- Assessment recommendations made.
- Certificate issued (5 year validity).
- Surveillance (yearly).

This process, from application to issuing of the certificate, can take months to complete.

3.4.2 Welding co-ordination

A key part of BS EN ISO 3834 is the definition of responsibilities of the welding co-ordination personnel. ISO 14731 defines these personnel and the technical knowledge that they require. The main role falls to the Responsible Welding Co-ordinator (RWC).

One or more personnel in a company may perform the welding co-ordination function, but each of the requirements of BS EN ISO 3834 listed above will require input from the welding co-ordination team.

Table 1 in BS EN ISO 14731 gives guidance for those tasks which may require a welding co-ordinator input. The technical knowledge required from the co-ordinator will obviously depend upon the complexity of the product.

The standard defines three levels of knowledge and experience:

- 1 **Comprehensive:** Equivalent to the level of an International/European Welding Engineer.
- 2 **Specific:** Equivalent to the level of an International/European Welding Technologist.
- 3 **Basic:** Equivalent to the level of an International/European Welding Specialist.

It can be seen that the three levels of technical knowledge are defined to match with the three levels of quality requirements given in Parts 2-4 of BS EN ISO 3834.

The IIW route is not mandatory; there are in fact three possible routes to demonstrate technical knowledge:

- 1 IIW qualification and experience (via interview).
- 2 Interview to assess knowledge without IIW qualification (professional review in 3834 audit).
- 3 Sub-contract to an external resource with appropriate knowledge and experience; again, an interview is required (it would be expected that the external resource will be familiar with the company applying for certification and will be contracted to visit regularly).

3.5 Calibration/validation of welding equipment

Faulty equipment compromises the quality of work. It follows that any equipment used in production, or for welder and procedure approval tests, should be in a sound condition in all respects in order to avoid breakdown during production or testing.

One important point to note is the accuracy of meters and the repeatability of the machine's controls in relation to output performance. Welding current connections and return leads on all arc welding equipment should be checked for tightness prior to commencing welding; failure to do so may lead to voltage losses affecting arcing conditions.

Where semi-automatic gas shielded processes are used, care should also be taken to ensure that the wire feeding systems are repeatable and accurate. Additionally, flowmeters controlling shielding and purging gases are expected to be calibrated.

This activity is collectively known as validation.

A requirement in many industries during the welding operation is the use of a calibrated meter(s) to check the welding current, arc voltages, travel speed and, on occasion, wire feed speed.

In addition, it must be ensured that the welders are using the correct gas, the electrode wires are of the correct composition and the preheat temperature and location have been applied in accordance with the welding procedure requirements.

In the case of manual metal arc (MMA) and submerged-arc welding (SAW), attention should be paid to any special drying requirements for fluxes or covered electrodes and also the conditions they are kept in prior to use. The use of a written procedure for storage and handling of consumables is recommended and records of humidity and temperature may be required to be kept.

Section 4

Codes and Standards

4 Codes and Standards

The control of quality in a fabrication and welding situation is achieved by working to company procedures and codes of construction or standards. The latter may be international, national, company's own or specific to the particular client or contract.

Company procedures are usually covered in quality manuals the scope of which may vary widely depending upon the size of company, its range of work, its working practices and many other factors.

4.1 Company manuals

4.1.1 Quality assurance manual

Quality assurance is defined in ISO 9000 as; part of quality management focused on providing confidence that quality requirements will be fulfilled.

Essentially what the QA manual sets out is how the company is organised, to lay down the responsibilities and authority of the various departments, how these departments interlink. The manual usually covers all aspects of the company structure, not just those aspects of manufacture.

4.1.2 Quality control manual

Quality control is defined in ISO 9000 as; part of quality management focused on fulfilling quality requirements.

The QC manual will be the manual most often referred to by the SWI as it will spell out in detail how different departments and operations are organised and controlled.

Typical examples would be: production and control of drawings, how materials and consumables are purchased, how welding procedures are produced, etc.

Essentially all operations to be carried out within the organisation will have control procedures laid down.

In particular it will lay down how the **Inspection** function, whether visual, dimensional or NDT, will be performed, inspection being defined as the activity of measuring, examining and testing characteristics of a product or service and comparing these to a specified requirement. Such requirements are laid down in codes of practice and standards.

4.2 Auditing

Auditing is a term originating from accountancy practice which involves an independent accountant checking the accounts of a company to see if the accounts are fair and accurate. A similar checking process is now widely practised in manufacturing and construction industries and inspection personnel will be involved in the carrying out of this operation.

Different types of audits may be performed:

- Full audit of a company, usually carried out by a third party such as a Certifying Authority, checking the company for the award of a QA accreditation system such as ISO 9000 or ASME stamp.
- Major audit by a potential customer prior to placement of a large contract. This is usually carried out to demonstrate the company has all the necessary facilities, plant, machinery, personnel and quality systems in place to enable them to successfully complete the contract.
- Part audits carried out as ongoing demonstration that the quality system is working properly.

An example of the latter case would be where a Senior Inspector is responsible for signing-off the data book or release certificate for a product. After checking that all the necessary documents are in the package and that they have been correctly completed and approved where necessary, the SWI would look at a part of the job – a beam, a piece of pipework etc and crosscheck against the drawings, mill certificates, inspection reports etc that all comply with the job requirements.

4.3 Codes and standards

It is not necessary for the Inspector to carry a wide range of codes and standards in the performance of his/her duties. Normally the specification or more precisely the contract specification is the only document required. However the contract specification may reference supporting codes and standards and the inspector should know where to access these normative documents.

The following is a list of definitions relating to codes and standards which the Inspector may come across whilst carrying inspection duties

4.3.1 Definitions

Normative document:

Provides rules, guidelines or characteristics for activities or their results.

The term normative document is generic and covers documents such as standards, technical specifications, codes of practice and regulations.*

Standard

Document established by consensus and approved by a recognised body.

A standard provides, for common and repeated use, guidelines, rules, and characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context.*

Harmonised standards

Standards on the same subject approved by different standardising bodies, that establish interchangeability of products, processes and services, or mutual understanding of test results or information provided according to these standards*

Code of practice

Document that recommends practices or procedures for the design, manufacture, installation, maintenance, utilisation of equipment, structures or products.

A code of practice may be a standard, part of a standard or independent of a standard.*

Regulation

Document providing binding legislative rules that is adopted by an authority.*

Authority

Body (responsible for standards and regulations legal or administrative entity that has specific tasks and composition) that has legal powers and rights.*

Regulatory authority

Authority responsible for preparing or adopting regulations.*

Enforcement authority

Authority responsible for enforcing regulations.*

Specification

A document stating requirements, needs or expectations.

A specification could cover both physical and technical requirements ie visual inspection, NDT, Mechanical testing etc. essentially full data and its supporting medium. Specifications are generally implied or obligatory.

Procedure

Specified way to carry out an activity or a process.* Usually it is a written description of all essential parameters and precautions to be observed when applying a technique to a specific application following an established standard, code or specification

Instruction

Written description of the precise steps to be followed based on an established procedure, standard, code or specification.

Quality plan

A document specifying which procedures and associated resources shall be applied by whom and when to a specific project, product, process or contract.*

* ISO IEC Guide 2 – Standardisation and related activities – General vocabulary.

** EN ISO 9000 – 2000 – Quality management systems – Fundamentals and vocabulary.

4.4 Summary

Application of the requirements of the quality manuals, the standards and codes of practice ensure that a structure or component will have an acceptable level of quality and be fit for the intended purpose.

Applying the requirements of a standard, code of practice or specification can be a problem for the inexperienced Inspector. Confidence in applying the requirements of one or all of these documents to a specific application only comes with use over a period of time.

If in doubt the Inspector must always refer to a higher authority in order to avoid confusion and potential problems.

Section 5

Fe-C Steels

5 Fe-C Steels

Pure iron is very soft and expensive to manufacture and thus has limited practical engineering applications. However, as we've already seen, as ferrous alloys can go through different phase changes depending on composition and temperature, the properties and particularly the strength, ductility and toughness can be tailored through alloying and thermal cycling (heat treatment or welding for example).

Of all the alloying elements used in steels, by far the most important one is carbon (C) and steels are defined as iron alloys containing less than 2% C. Ferrous alloys of more than 2% carbon content on the other hand are called cast irons.

Many other elements can also be present in steels, both intentionally added alloying elements and residual elements present from ore or scrap metal used in the steelmaking process.

5.1 Steel terminology

The terminology used to describe and specify different steel products can be confusing as these can be based on a combination of:

- Product form (sheet, plate, bar, sections, pipe or wire).
- Deoxidation practice (killed, semi-killed).
- Manufacturing route such as cast, forged, rolled, extruded.
- Heat treatment such as annealed, normalised and quench and tempered, which are used to achieve properties.
- Cleanliness level in terms of impurities such as sulphur and phosphorous.
- Finishing methods such as cold rolled or hot rolled.
- Presence or not of corrosion protection coatings.
- And so on.

To add to the confusion, different industry sectors use different nomenclatures and definitions to refer to the same alloys. A simplified terminology is used here which is widely used and is relevant to welding, but be aware that other terminologies also exist.

In a broad sense, non-stainless steels can be divided into two major groups: Carbon steel (also called C-Mn steels, depending on Mn level) and low alloy steels. This nomenclature is used in American standards (American Iron and Steel Institute and The Society of Automotive Engineering) and in modified forms in European standards as well.

5.1.1 Carbon steels

In many industry sectors, carbon steel is the usual description used to refer to any steel that is not stainless. Carbon is the single most important alloying element in steel and a wide range of properties is possible simply by changing its content. Strength can be increased very cost effectively by retaining more carbon in the composition (remember, carbon is already present from the primary steelmaking process and is in fact removed as part of steel refining). However, when welded it is well recognized that HAZ toughness decreases and risk of cracking during welding increases with carbon addition and welding becomes more challenging. Surprisingly though, in some particular applications such as in welded rail tracks this trade-off can be overcome and steels which are often of eutectic composition with carbon content of 0.76% are used!!

As shown below, hardness and strength can be achieved simply by increasing the carbon content of the alloy. This however comes at a cost, not only in terms of welding but also in terms of mechanical properties as ductility and toughness also deteriorate with increasing carbon content.

Carbon steels can be divided (broadly) into plain carbon and carbon-manganese steels:

Plain carbon steels are the most widely used steel type. These are usually specified based on carbon content (example, AISI 1010 and 1018 carbon steels have target carbon contents of approximately 0.1 and 0.18, respectively) and are limited to a maximum of 1% manganese. The microstructures of plain carbon steels are based around the thermodynamic equilibrium microstructures of ferrite and pearlite.

Carbon-manganese (C-Mn) steels are similar to plain carbon steels except that C-Mn steels have higher Mn contents of between 1 and 1.65 weight %. Manganese is used for deoxidation (to remove oxygen from the melt during steelmaking), as a solid solution strengthener and also can have the effect of lowering the ductile to brittle transition temperature. However, addition of manganese also increases the hardenability of steels which could be a drawback when welding as will be shown later in this section.

5.1.2 Low Alloy steels

Some alloying elements increase the hardenability of steels, that is, they delay the transformation from austenite to the equilibrium microstructures of ferrite and pearlite to longer times, thus giving more opportunity for non-equilibrium microstructures such as martensite to form during cooling. Alloys specified based on element additions to increase hardenability to achieve designated strength, ductility and toughness requirements are called low alloy steels. In general, total alloy content does not exceed 5%.

Martensite is achieved with a sufficient level of carbon or other elements and a sufficiently rapid cooling rate. It has high strength and hardness but can be very brittle, so a softening (tempering) heat treatment is normally applied to improve toughness during the manufacturing process. This is not always possible after welding and these steels require special precautions during welding to obtain good enough properties in the HAZ and to avoid hydrogen cracking.

Note: In some industry sectors stainless steels are referred to as alloy steels (minimum of 10% alloying), which is probably why low-alloy-steel is used to describe steels with high hardenability (quenched and tempered for example) as these have much lower alloy content compared to stainless grades. Comparing with C-Mn steels however, these are relatively high alloyed steel grades with much higher hardenability.

5.1.3 High strength low alloy steels

For the parent material, an alternative approach to increase strength without increasing carbon content is grain refinement which not only increases strength but also increases toughness. This family of fine grained high strength steels (up to 560MPa yield) with low carbon and lean general composition are called high strength low alloy steels.

Contrary to low-alloy-steels which can in fact be quite highly alloyed, HSLA steels are truly low alloyed steels and the strength is achieved through refinement of the microstructure rather than by significant alloying additions. For the same strength level, an HSLA alloy will have a much leaner composition to its C-Mn equivalent. The microstructure of HSLA steels is still generally ferrite and pearlite but will usually contain very small amounts of pearlite.

The manufacturing routes to achieve the necessary microstructure refinement were covered in Section 6 (Heat treatment of steels).

To refresh your memory

HSLA steels rely on very small alloying additions of vanadium, niobium and/or titanium and controlled rolling as well as defined and narrow temperature ranges. Because the additions of V, Nb and Ti are so small these are also called micro-alloyed steels.

Particularly in the oil and gas industry, a slight variation of the controlled rolling process is used where micro-alloying is used to obtain a fine-grain structure during the hot rolling process followed by accelerated cooling at the end of the hot rolling process to promote a bainitic or acicular ferrite microstructure. These alloys are called Thermo-mechanically controlled process (TMCP) steels.

Section 6

Destructive Testing

6 Destructive Testing

European Welding Standards require test coupons that are made for welding procedure qualification testing to be subjected to non-destructive testing and then destructive testing.

The tests are called destructive tests because the welded joint is destroyed when various types of test piece are taken from it.

Destructive tests can be divided into 2 groups, those used to:

- Measure a mechanical property – **quantitative tests**
- Assess the joint quality – **qualitative tests**

Mechanical tests are quantitative because a quantity is measured – a mechanical property such as tensile strength, hardness and impact toughness.

Qualitative tests are used to verify that the joint is free from defects – they are of sound quality, examples of these are bend tests, macroscopic examination and fracture tests (fillet fracture and nick-break).

6.1 Test types, test pieces and test objectives

Various types of mechanical tests are used by material manufacturers and suppliers to verify that plates, pipes, forgings, etc. have the minimum property values specified for particular grades.

Design engineers use the minimum property values listed for particular grades of material as the basis for design and the most cost-effective designs are based on an assumption that welded joints have properties that are no worse than those of the base metal.

The quantitative (mechanical) tests that are carried out for welding procedure qualification are intended to demonstrate that the joint properties satisfy design requirements.

The emphasis in the following sub-sections is on the destructive tests and test methods that are widely used for welded joints.

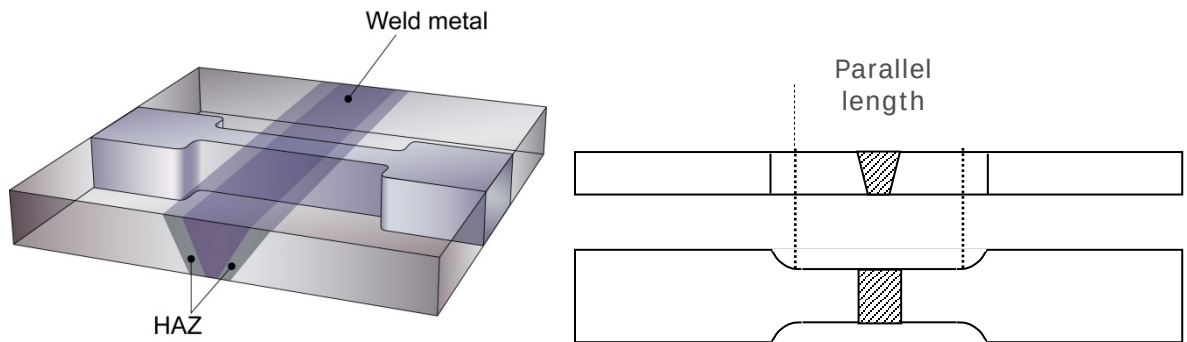
6.1.1 Transverse tensile tests

Test objective

Welding procedure qualification tests always require transverse tensile tests to show that the strength of the joint satisfies the design criterion.

Test specimens

A transverse tensile test piece typical of the type specified by European Welding Standards is shown below.



Standards, such as EN 895, that specify dimensions for transverse tensile test pieces require all excess weld metal to be removed and the surface to be free from scratches.

Test pieces may be machined to represent the full thickness of the joint but for very thick joints it may be necessary to take several transverse tensile test specimens to be able to test the full thickness.

Test method

Test specimens are accurately measured before testing. Specimens are then fitted into the jaws of a tensile testing machine and subjected to a continually increasing tensile force until the specimen fractures.

The tensile strength (R_m) is calculated by dividing the maximum load by the cross-sectional area of the test specimen - measured before testing.

The test is intended to measure the **tensile strength of the joint** and thereby show that the basis for design, the base metal properties, remains the valid criterion.

Acceptance criteria

If the test piece breaks in the weld metal, it is acceptable provided the calculated strength is not less than the minimum tensile strength specified, which is usually the minimum specified for the base metal material grade.

In the ASME IX code, if the test specimen breaks outside the weld or fusion zone at a stress above 95% of the minimum base metal strength the test result is acceptable.

6.1.2 All-weld tensile tests

Test objective

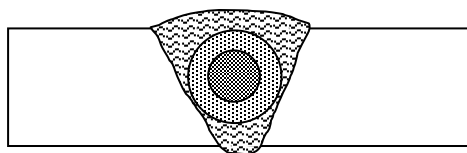
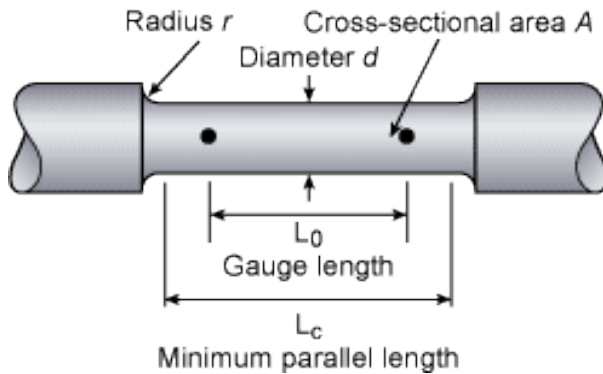
There may be occasions when it is necessary to measure the weld metal strength as part of welding procedure qualification – particularly for elevated temperature designs.

The test is carried out in order to measure not only tensile strength but also yield (or proof strength) and tensile ductility.

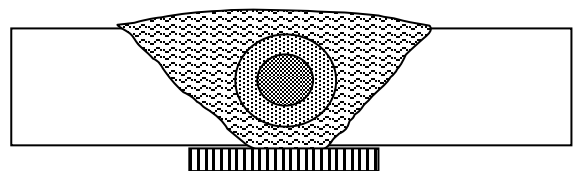
All weld tensile tests are also regularly carried out by welding consumable manufacturers to verify that electrodes and filler wires satisfy the tensile properties specified by the standard to which the consumables are certified.

Test specimens

As the name indicates, test specimens are machined from welds parallel with their longitudinal axis and the specimen gauge length must be 100% weld metal.



Round tensile specimen from a welding procedure qualification test piece.



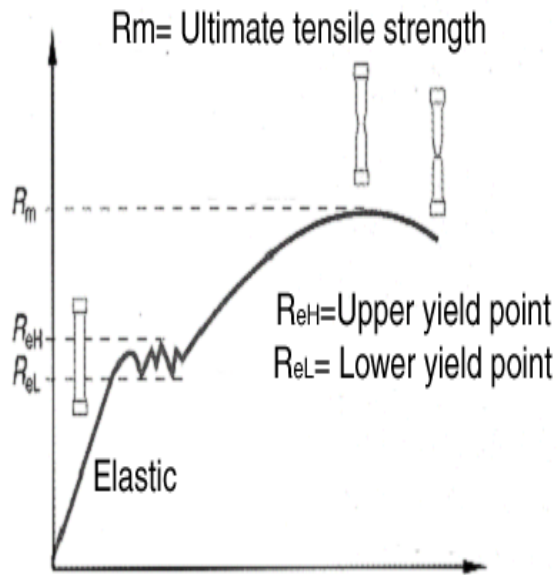
Round tensile specimen from an electrode classification test piece.

Test method

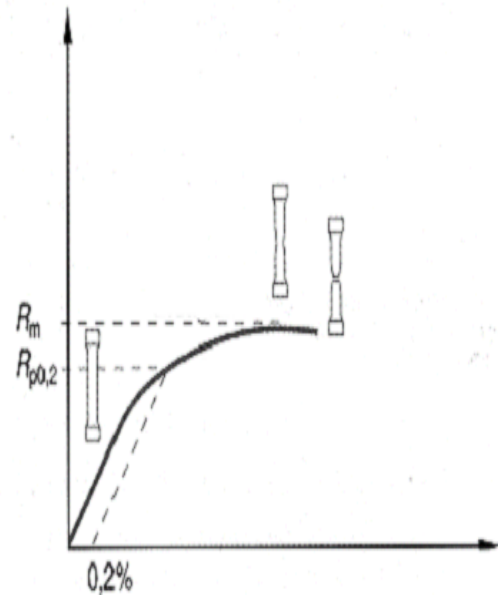
Specimens are subjected to a continually increasing force in the same way that transverse tensile specimens are tested.

Yield (R_e) or proof stress (R_p) are measured by means of an extensometer that is attached to the parallel length of the specimen and is able to accurately measure the extension of the gauge length as the load is increased.

Typical load extension curves and their principal characteristics are shown below.



Load-extension curve for a steel that shows a distinct yield point at the elastic limit.

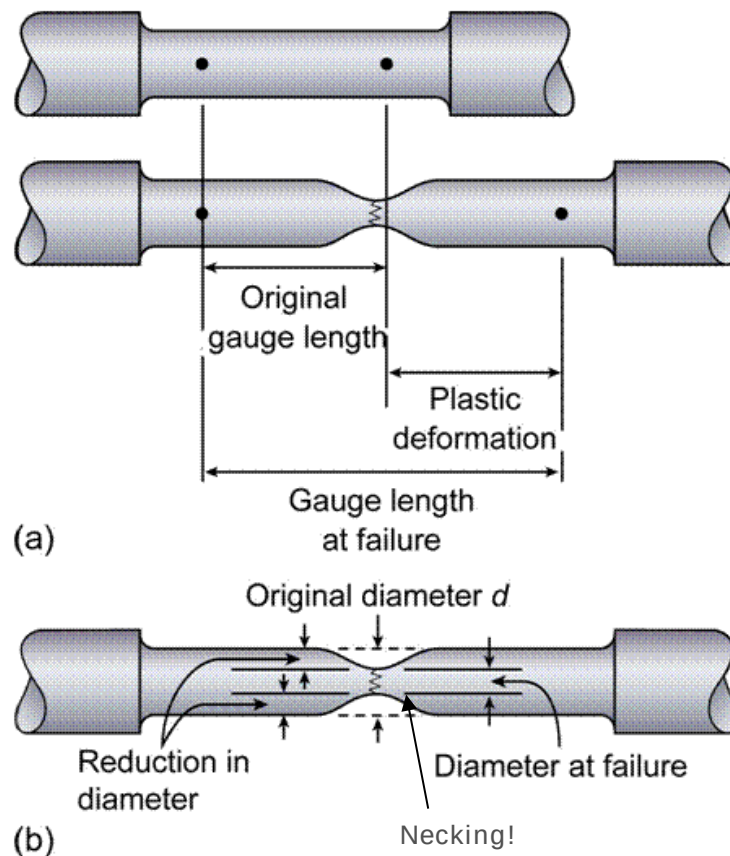


Load-extension curve for a steel (or other metal) that does not show a distinct yield point; proof stress is a measure of the elastic limit.

Tensile ductility is measured in two ways:

- 1 % elongation of the gauge length (A%).
- 2 % reduction of area at the point of fracture (Z%).

The figures below illustrate these two ductility measurements.



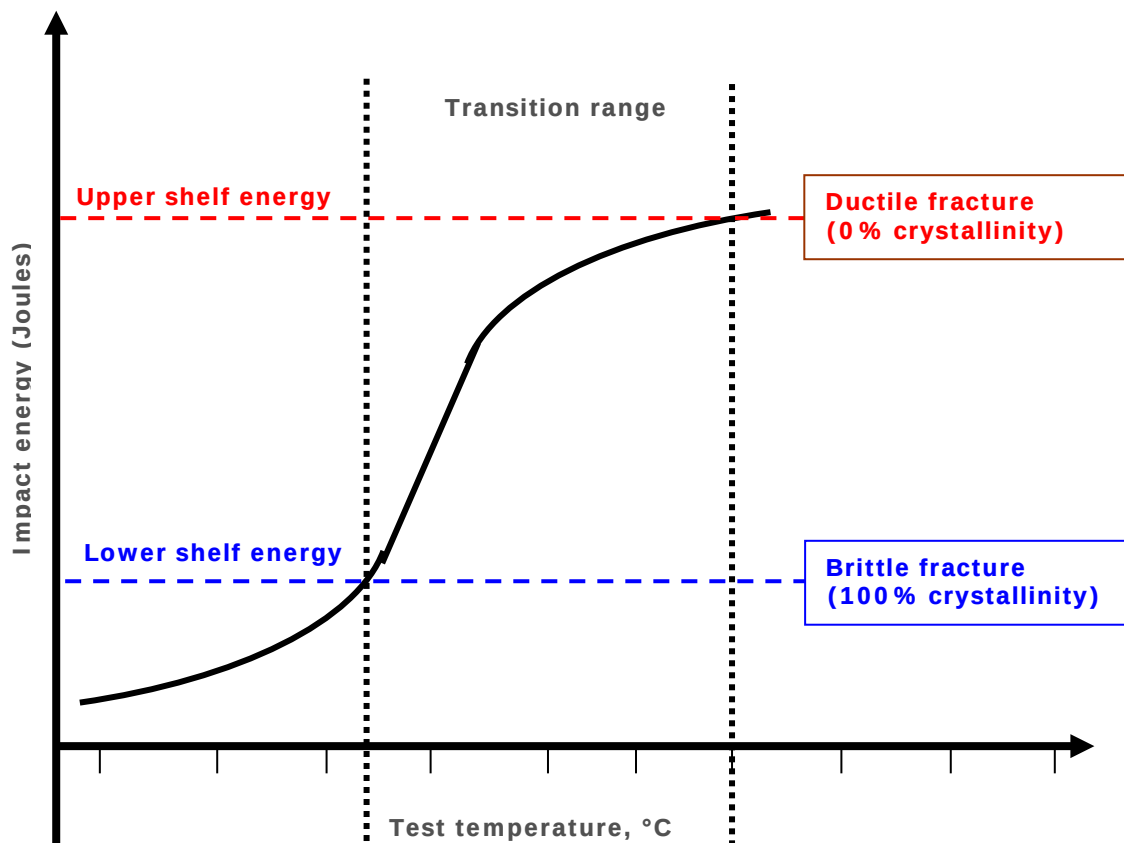
6.1.3 Impact toughness tests

Test objective

Charpy V notch test pieces have become the internationally accepted method for assessing resistance to brittle fracture by measuring the energy to initiate, and propagate, a crack from a sharp notch in a standard sized specimen subjected to an impact load. **The value achieved is known as the notch or impact toughness.**

Design engineers need to ensure that the toughness of the steel that is used for a particular item will be high enough to avoid brittle fracture in service and so impact specimens are tested at a temperature that is related to the design temperature for the fabricated component.

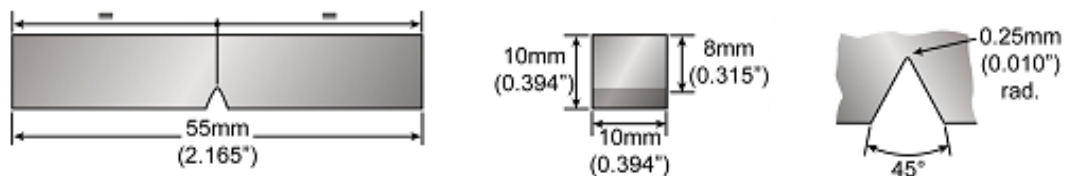
C-Mn and low alloy steels undergo a sharp change in their resistance to brittle fracture as their temperature is lowered so that a steel that may have very good toughness at ambient temperature may show extreme brittleness at sub-zero temperatures, as illustrated in following figure.



The transition temperature is defined as the temperature mid-way between the upper shelf (maximum toughness) and lower shelf (completely brittle). In the above the transition temperature is -20°C .

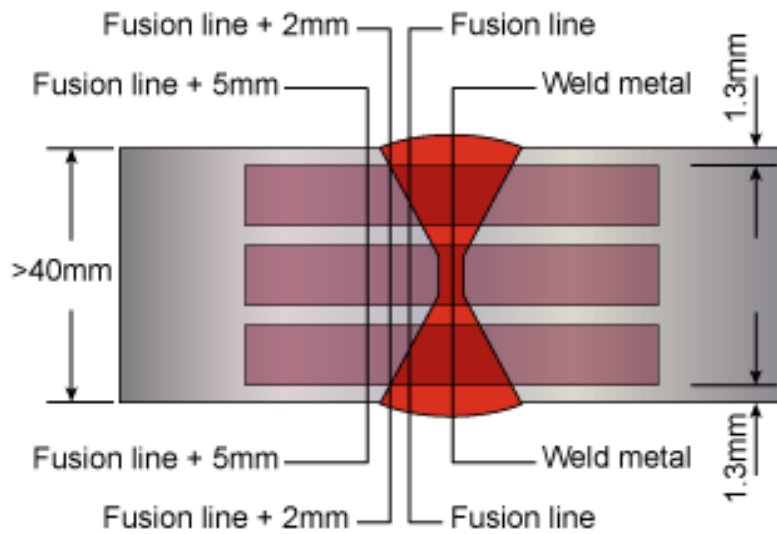
Test specimens

The dimensions for test specimens have been standardised internationally and are shown below for **full sized specimens**. There are also standard dimensions for smaller sized specimens, for example 10mm x 7.5mm and 10mm x 5mm.



Charpy V notch test piece dimensions for full sized specimens.

Specimens are machined from welded test plates with the notch position located in different locations according to the testing requirements but typically in the centre of the weld metal and at positions across the HAZ – as shown below.



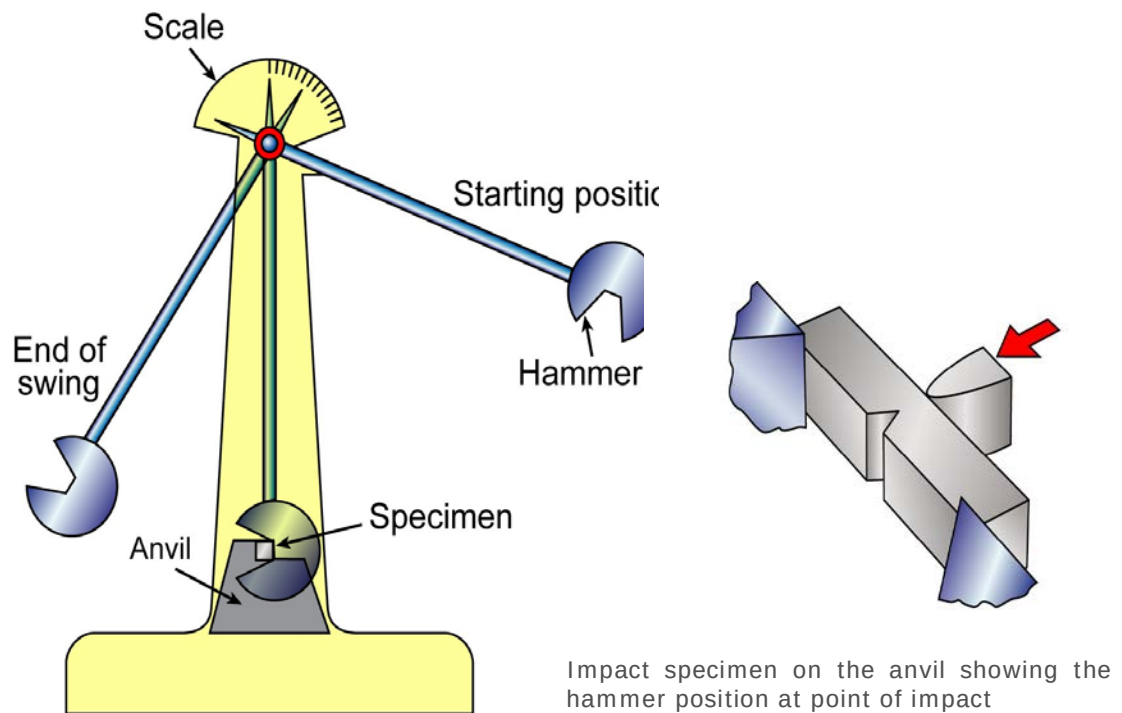
Typical notch positions for Charpy V notch test specimens from double V butt welds.

Test method

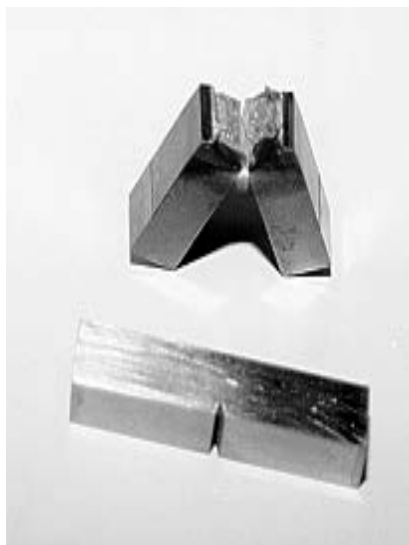
Test specimens are cooled to the specified test temperature by immersion in an insulated bath containing a liquid that is held at the test temperature.

After allowing the specimen temperature to stabilise for a few minutes it is quickly transferred to the anvil of the test machine and a pendulum hammer quickly released so that the specimen experiences an impact load behind the notch.

The main features of an impact test machine are shown below.



Impact testing machine



Charpy V notch test pieces
– before and after testing

The energy absorbed by the hammer when it strikes each test specimen is shown by the position of the hammer pointer on the scale of the machine. Energy values are given in Joules (or ft-lbs in US specifications).

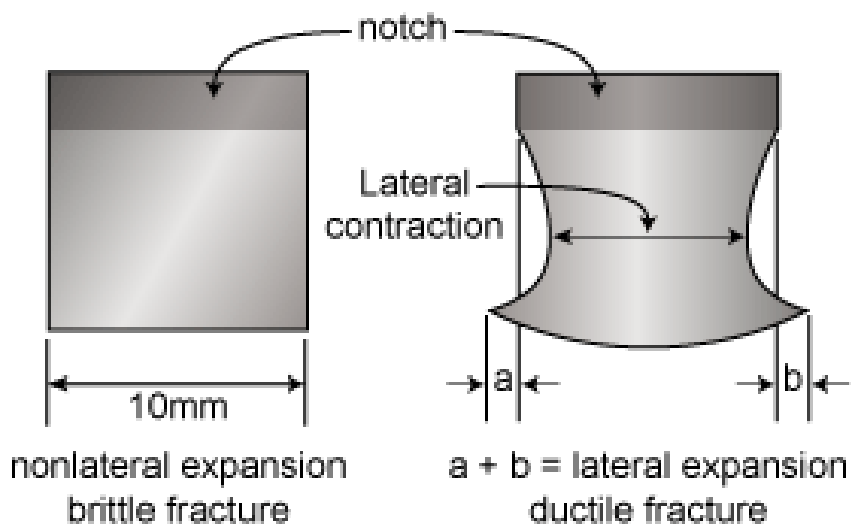
Impact test specimens are taken in triplicate (3 specimens for each notch position) as there is always some degree of scatter in the results, particularly for weldments.

Acceptance criteria

Each test result is recorded and an average value calculated for each set of three tests. These values are compared with the values specified by the application standard or client to establish whether specified requirements have been met.

After impact testing, examination of the test specimens provides additional information about their toughness characteristics and may be added to the test report:

- % crystallinity – the % of the fracture face that has crystalline appearance which indicates brittle fracture; 100% indicates completely brittle fracture.
- Lateral expansion – the increase in width of the back of the specimen behind the notch – as indicated below; the larger the value the tougher the specimen.



A specimen that exhibits extreme brittleness will show a clean break. Both halves of the specimen having a completely flat fracture face with little or no lateral expansion.

A specimen that exhibits very good toughness will show only a small degree of crack extension, without fracture and a high value of lateral expansion.

6.1.4 Hardness testing

Test objectives

The hardness of a metal is its' resistance to plastic deformation determined by measuring the resistance to indentation by a particular type of indenter.

A steel weldment with hardness above a certain maximum may be susceptible to cracking, either during fabrication or in service, and welding procedure qualification testing for certain steels and applications that require the test weld to be hardness surveyed to ensure that are no regions of the weldment that exceed the maximum specified hardness.

Specimens prepared for macroscopic examination can also be used for taking hardness measurements at various positions of the weldment – referred to as a **hardness survey**.

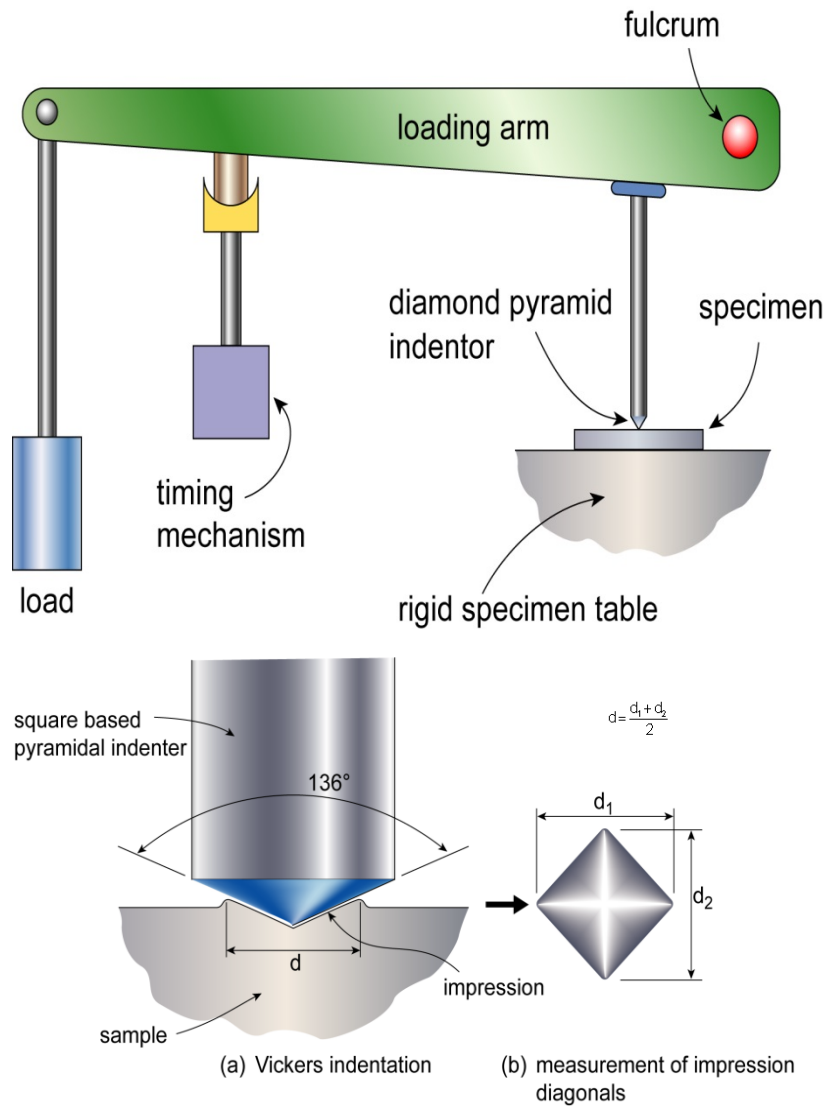
Test methods

There are 3 widely used methods for hardness testing:

- 1 Vickers hardness test uses a square-base diamond pyramid indenter.
- 2 Rockwell hardness test uses a diamond cone indenter or steel ball.
- 3 Brinell hardness test uses a ball indenter.

The hardness value being given by the size of the indentation produced under a standard load, the smaller the indentation, the harder the metal.

The Vickers method of testing is illustrated below.

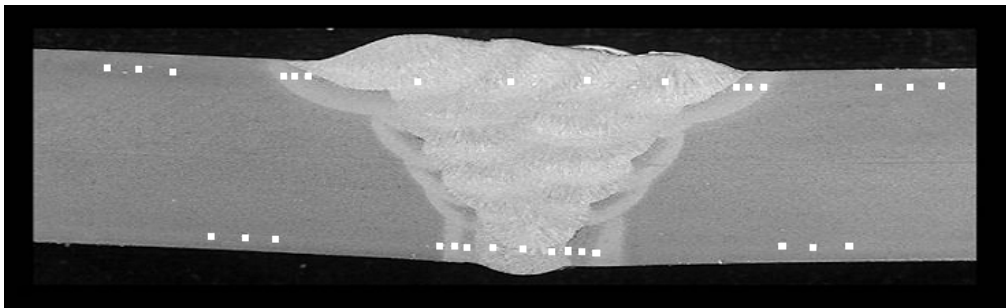


Both Vickers and Rockwell methods are suitable for carrying out hardness surveys on specimens prepared for macroscopic examination of weldments.

A typical hardness survey requires the indenter to measure the hardness in the base metal (on both sides of the weld), in the weld metal and across the HAZ (on both sides of the weld).

The Brinell method gives an indentation that is too large to accurately measure the hardness in specific regions of the HAZ and is mainly used to measure hardness of base metals.

A typical hardness survey (using Vickers hardness indenter) is shown below:



Hardness values are shown on test reports as a number followed by letters indicating the test method, for example:

240HV10 = hardness 240, Vickers method, 10kg indenter load.

22HRC = hardness 22, Rockwell method, diamond cone indenter (scale C).

238HBW = 238 hardness, Brinell method, tungsten ball indenter.

6.1.5 Crack tip opening displacement (CTOD) testing

Test objective

Charpy V notch testing enables engineers to make judgements about risks of brittle fracture occurring in steels, but a CTOD test measures a material property - **fracture toughness**.

Fracture toughness data enables engineers to carry out fracture mechanics analyses such as:

- Calculating the size of a crack that would initiate a brittle fracture under certain stress conditions at a particular temperature.
- The stress that would cause a certain sized crack to give a brittle fracture at a particular temperature.

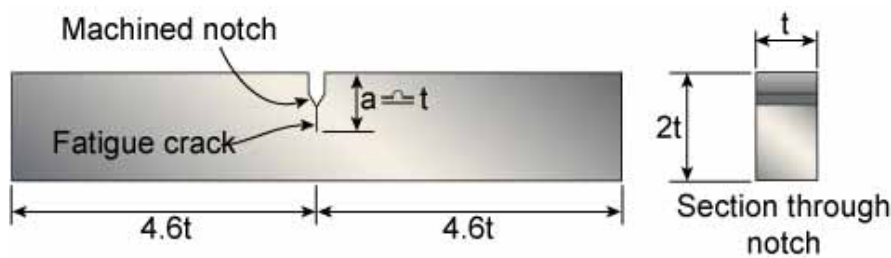
This data is essential for making an appropriate decision when a crack is discovered during inspection of equipment that is in-service.

Test specimens

A CTOD specimen is prepared as a rectangular (or square) shaped bar cut transverse to the axis of the butt weld. A V notch is machined at the centre of the bar, which will be coincident with the test position - weld metal or HAZ.

A shallow saw cut is then put into the bottom of the notch and the specimen is then put into a machine that induces a cyclic bending load until a shallow fatigue crack initiates from the saw cut.

The specimens are relatively large – typically having a cross section $B \times 2B$ and length $\sim 10B$ (B = full thickness of the weld). The test piece details are shown below.



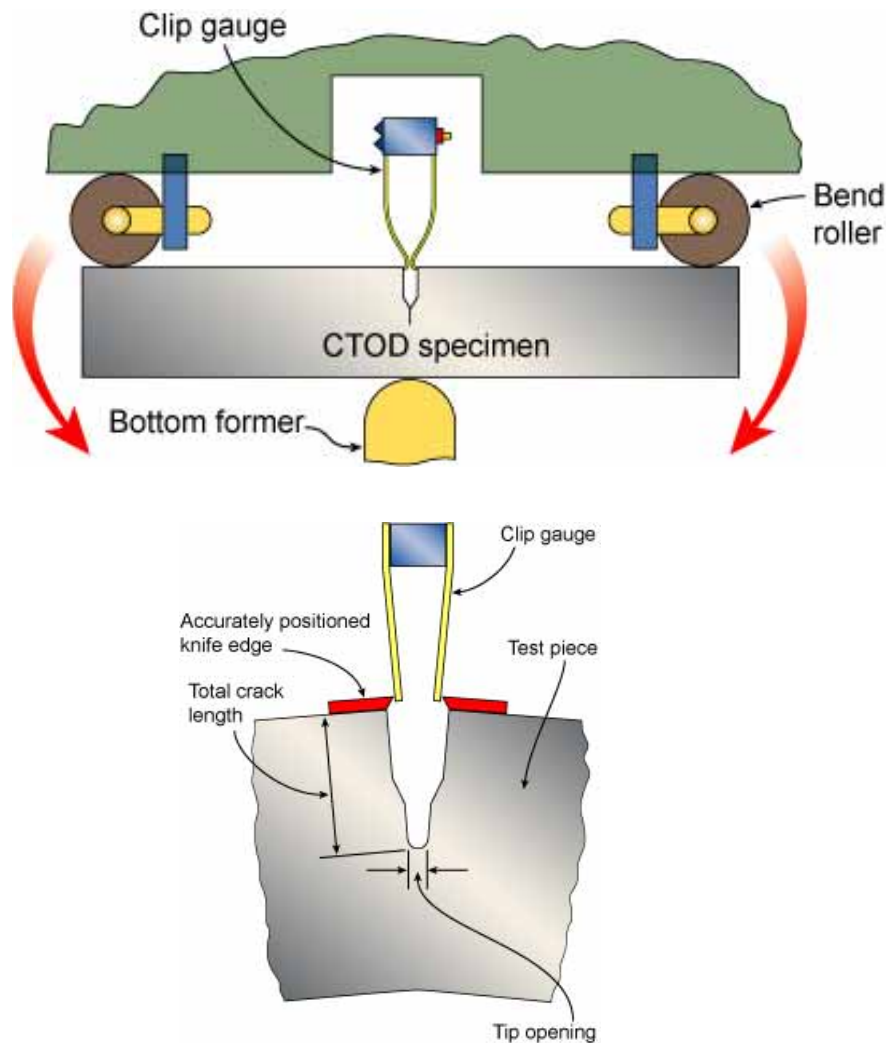
Test method

CTOD specimens are usually tested at a temperature below ambient and the temperature of the specimen is controlled by immersion in a bath of liquid that has been cooled to the required test temperature.

A load is applied to the specimen to cause bending and induce a concentrated stress at the tip of the crack and a clip gauge, attached to the specimen across the mouth of the machined notch, gives a reading of the increase in width of the mouth of the crack as the load is gradually increased.

For each test condition (position of notch and test temperature) it is usual practice to carry out three tests.

Below illustrates the main features of the CTOD test.



Fracture toughness is expressed as the distance that the crack tip opens without initiation of a brittle crack.

The clip gauge enables a chart to be generated showing the increase in width of the crack mouth against applied load from which a CTOD value is calculated.

Acceptance criteria

An application standard or client may specify a minimum CTOD value that indicates ductile tearing. Alternatively, the test may be for information so that a value can be used for an engineering critical assessment.

A very tough steel weldment will allow the mouth of the crack to open widely by ductile tearing at the tip of the crack whereas a very brittle weldment will tend to fracture when the applied load is quite low and without any extension at the tip of the crack.

CTOD values are expressed in millimetres - typical values might be $< \sim 0.1\text{mm}$ = brittle behaviour; $> \sim 1\text{mm}$ = very tough behaviour.

6.1.6 Bend testing

Test objective

Bend tests are routinely taken from welding procedure qualification test pieces and sometimes have to be taken from welder qualification test pieces.

Subjecting specimens to bending is a simple method of verifying that there are no significant flaws in the joint. Some degree of ductility is also demonstrated.

Ductility is not actually measured but is demonstrated to be satisfactory if test specimens can withstand being bent without fracture or fissures above a certain length.

Test specimens

There are 4 types of bend specimen:

Face bend

Specimen taken with axis transverse to butt welds up to ~12mm thickness and bent so that the face of the weld is on the outside of the bend (face in tension).

Root bend

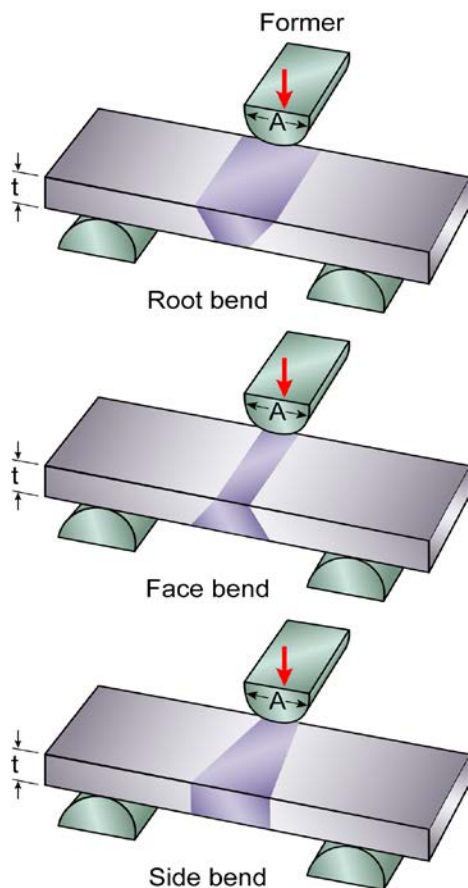
Test specimen taken with axis transverse to butt welds up to ~12mm thickness and bent so that the root of the weld is on the outside of the bend (root in tension).

Side bend

Test specimen taken as a transverse slice (~10mm) from the full thickness of butt welds >~12mm and bent so that the full joint thickness is tested (side in tension).

Longitudinal bend

Test specimen taken with axis parallel to the longitudinal axis of a butt weld; specimen thickness is ~12mm and the face or root of weld may be tested in tension.



Test method

Bend tests for welding procedure qualification (and welder qualification) are usually guided bend tests.

Guided means that the strain imposed on the specimen is uniformly controlled by being bent around a former with a certain diameter.

The diameter of the former used for a particular test is specified in the code, having been determined by the type of material that is being tested and the ductility that can be expected from it after welding and any PWHT.

The diameter of the former is usually expressed as a multiple of the specimen thickness and for C-Mn steel it is typically $4t$ (t is the specimen thickness) but for materials that have lower tensile ductility the radius of the former may be greater than $10t$.

The standard that specifies the test method will specify the minimum bend angle that the specimen must experience and this is typically $120-180^\circ$.

Acceptance criteria

Bend test pieces should exhibit satisfactory soundness by not showing cracks or any signs of significant fissures or cavities on the outside of the bend.

Small indications less than about 3mm in length may be allowed by some standards.

6.2 Fracture tests

6.2.1 Fillet weld fractures

Test objective

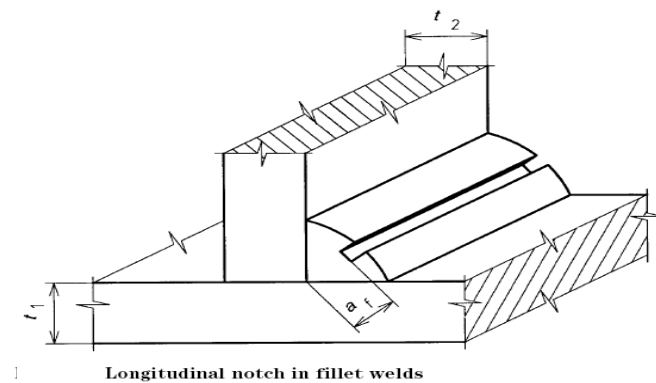
The quality/soundness of a fillet weld can be assessed by fracturing test pieces and examining the fracture surfaces.

This method for assessing the quality of fillet welds may be specified by application standards as an alternative to macroscopic examination.

It is a test method that can be used for welder qualification testing according to European Standards but is not used for welding procedure qualification to European Standards.

Test specimens

A test weld is cut into short lengths (typically $\geq 50\text{mm}$) and a longitudinal notch is machined into the specimen as shown below. The notch profile may be square, V or U shaped.



Test method

Specimens are made to fracture through their throat by dynamic strokes (hammering) or by pressing, as shown below. The welding standard or application standard will specify the number of tests (typically 4).

Acceptance criteria

The standard for welder qualification, or application standard, will specify the acceptance criteria for imperfections such as lack of penetration into the root of the joint and solid inclusions and porosity that are visible on the fracture surfaces.

Test reports should also give a description of the appearance of the fracture and location of any imperfection

Butt weld fractures (nick-break tests)

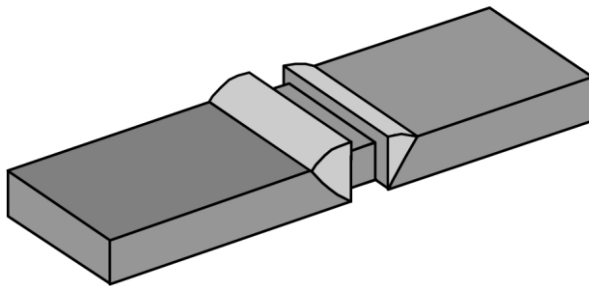
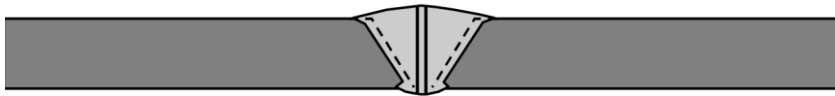
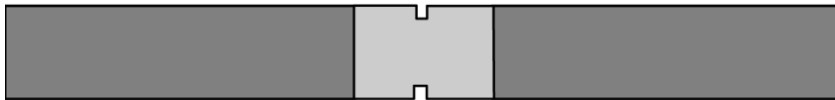
Test objective

The objective of these fracture tests is the same as for fillet fracture tests.

These tests are specified for welder qualification testing to European Standards as an alternative to radiography. They are not used for welding procedure qualification testing to EU Standards.

Test specimens

Test specimens are taken from a butt weld and notched so that the fracture path will be in the central region of the weld. Typical test piece types are shown below.



Test method

Test pieces are made to fracture by hammering or three-point bending.

Acceptance criteria

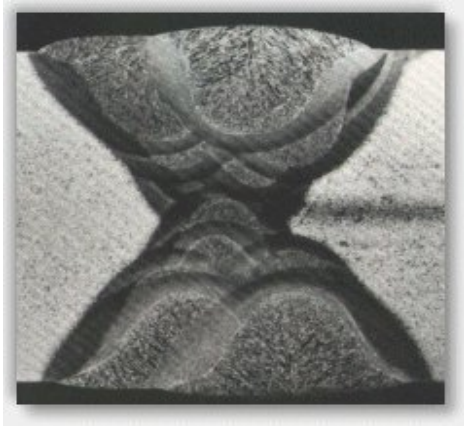
The standard for welder qualification, or application standard, will specify the acceptance criteria for imperfections such as lack of fusion, solid inclusions and porosity that are visible on the fracture surfaces.

Test reports should also give a description of the appearance of the fracture and location of any imperfection.

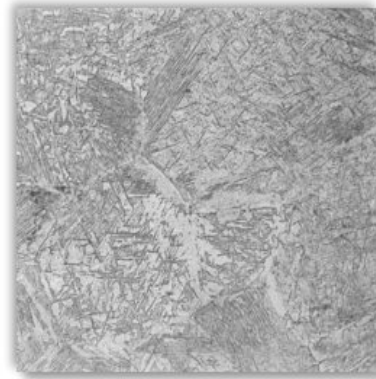
6.3 Macroscopic examination

Transverse sections from butt and fillet welds are required by the EU Standards for welding procedure qualification testing and may be required for some welder qualification testing for assessing the quality of the welds.

This is considered in detail in a separate section of these course notes.



Macro examination



Micro examination

Objectives

- Detecting weld defects. (macro).
- Measuring grain size. (micro).
- Detecting brittle structures, precipitates.
- Assessing resistance toward brittle fracture, cold cracking and corrosion sensitivity.

European Standards for Destructive Test Methods

The following Standards are specified by the European Welding Standards for destructive testing of welding procedure qualification test welds and for some welder qualification test welds.

BS EN ISO 9016

Destructive tests on welds in metallic materials – Impact tests – Test specimen location, notch orientation and examination.

BS EN ISO 4136

Destructive tests on welds in metallic materials – Transverse tensile test.

BS EN ISO 5173 + A1

Destructive tests on welds in metallic materials – Bend tests.

BS EN ISO 17639

Destructive tests on welds in metallic materials – Macroscopic and microscopic examination of weld.

BS EN ISO 6892-1

Metallic materials - Tensile testing. Part 1: Method of test at ambient temperature.

BS EN ISO 6892-2

Tensile testing of metallic materials. Part 2: Method of test at elevated temperatures.

TWI

Destructive Testing

Section 6

Materials Joining and Engineering Technologies
Training and Examination Services

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Destructive Testing Objective

When this presentation has been completed you should be able to:

- Recognise a wide range of mechanical tests and their purpose.
- Make calculations using formulae and tables to determine various values of strength, toughness, hardness and ductility.

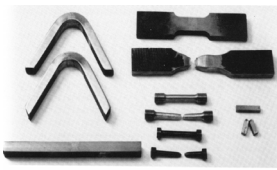
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Destructive Testing Definitions

What is Destructive Testing?

The destruction of a welded unit or by cutting out selected specimens from the weld is carried out to check the mechanical properties of the joint materials. They can be produced to:



- Approve welding procedures (BS EN 15614).
- Approve welders (BS EN 287).
- Production quality control.

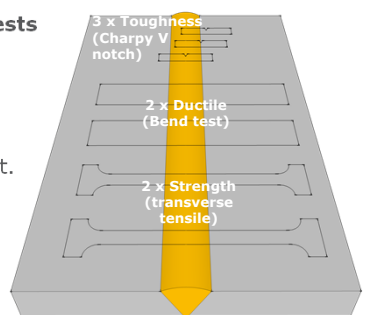
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Destructive Tests

Destructive tests includes

- Bend test.
- Impact test.
- Tensile test.
- Hardness test.
- Macro/micro examination.



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Qualitative and Quantitative Tests

The following mechanical tests have units and are termed **quantitative** tests to **measure mechanical properties** of the joint.

- Tensile tests (transverse welded joint, all weld metal).
- Toughness testing (Charpy, Izod, CTOD).
- Hardness tests (Brinell, Rockwell, Vickers).

The following mechanical tests have no units and are termed **qualitative** tests for **assessing weld quality**.

- Macro testing.
- Bend testing.
- Fillet weld fracture testing.
- Butt weld nick-break testing.

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Definitions

Mechanical Properties of metals

are related to the amount of deformation which metals can withstand under different circumstances of force application.

- Malleability
- Ductility
- Toughness
- Hardness
- Tensile Strength

Ability of a material to withstand deformation under static compressive loading without rupture

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Definitions

Mechanical Properties of metals are related to the amount of deformation which metals can withstand under different circumstances of force application.

- Malleability
- Ductility
- Toughness
- Hardness
- Tensile Strength

Ability of a material undergo plastic deformation under static tensile loading without rupture. Measurable elongation and reduction in cross section area

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Definitions

Mechanical Properties of metals are related to the amount of deformation which metals can withstand under different circumstances of force application.

- Malleability
- Ductility
- Toughness
- Hardness
- Tensile Strength

Ability of a material to withstand bending or the application of shear stresses by impact loading without fracture.

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Definitions

Mechanical Properties of metals are related to the amount of deformation which metals can withstand under different circumstances of force application.

- Malleability
- Ductility
- Toughness
- Hardness
- Tensile Strength

Measurement of a materials surface resistance to indentation from another material by static load

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Definitions

Mechanical Properties of metals are related to the amount of deformation which metals can withstand under different circumstances of force application.

- Malleability
- Ductility
- Toughness
- Hardness
- Tensile Strength

Measurement of the maximum force required to fracture a materials bar of unit cross-sectional area in tension

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Mechanical Test Samples

CTOD specimen

Charpy specimen

Tensile specimens

Bend test specimen

Fracture fillet specimen

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Destructive Testing

Welding Procedure Qualification Testing

Top of fixed pipe

Typical positions for test pieces

Specimen type	Position
Macro + hardness	5
Transverse tensile	2, 4
Bend tests	2, 4
Charpy impact tests	3
Additional tests	3

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Mechanical Testing

Hardness Testing

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Hardness Testing

Definition

- Measurement of resistance of a material against penetration of an indenter under a constant load.
- There is a direct correlation between UTS and hardness.

Hardness tests

- Brinell.
- Vickers.
- Rockwell.

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Hardness Testing

Objectives

- Measuring hardness in different areas of a welded joint.
- Assessing resistance toward brittle fracture, cold cracking and corrosion sensitivity.

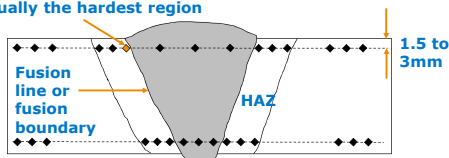
Information to be supplied on the test report

- Material type.
- Location of indentation.
- Type of hardness test and load applied on the indenter.
- Hardness value.

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Hardness Testing



Usually the hardest region

Fusion line or fusion boundary

HAZ

1.5 to 3mm

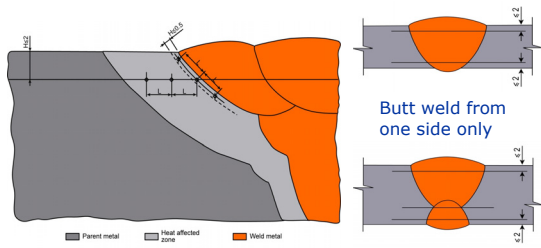
Hardness test methods	Typical designations
Vickers	240 HV10
Rockwell	Rc 22
Brinell	200 BHN-W

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Vickers Hardness Test

Typical location of the indentations



Butt weld from one side only

Butt weld from both side

(Dimensions in millimetres)

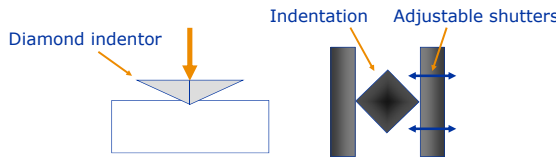
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Vickers Hardness Test

Vickers hardness tests

- Indentation body is a square based diamond pyramid (136° included angle).
- The average diagonal (d) of the impression is converted to a hardness number from a table.
- It is measured in HV5, HV10 or HV025.

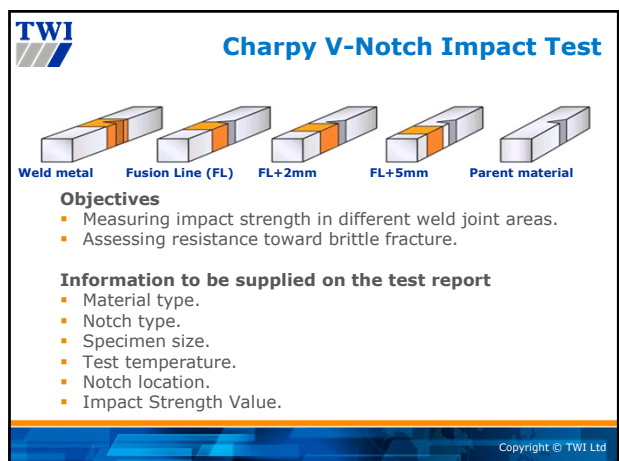
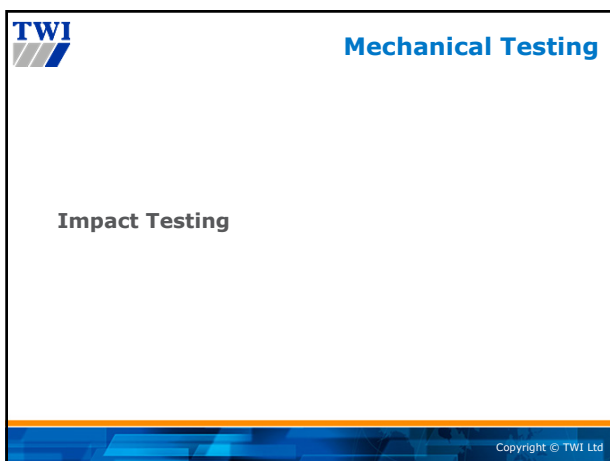
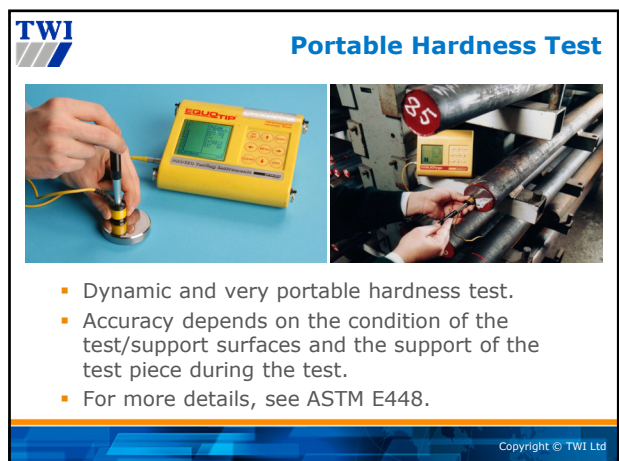
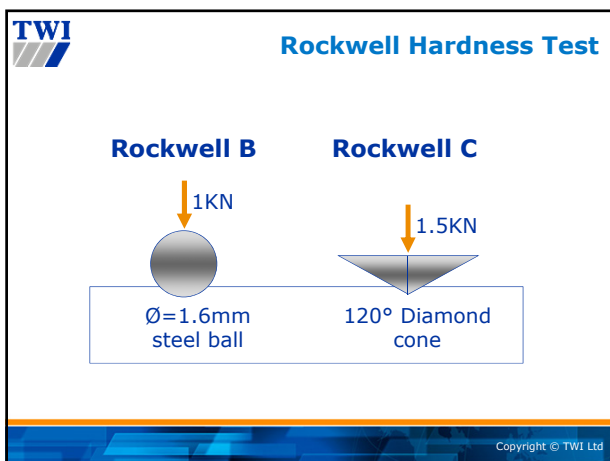
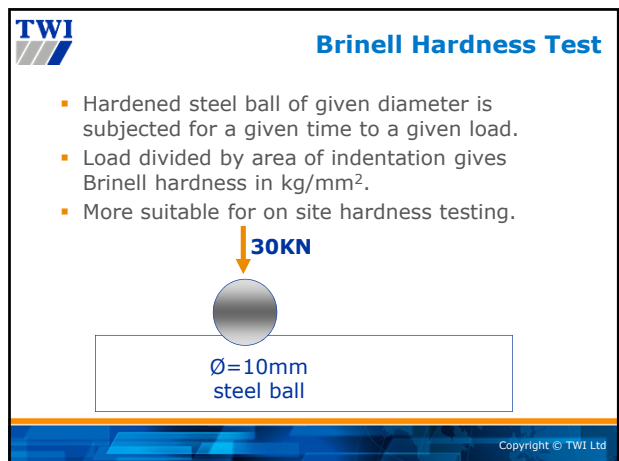
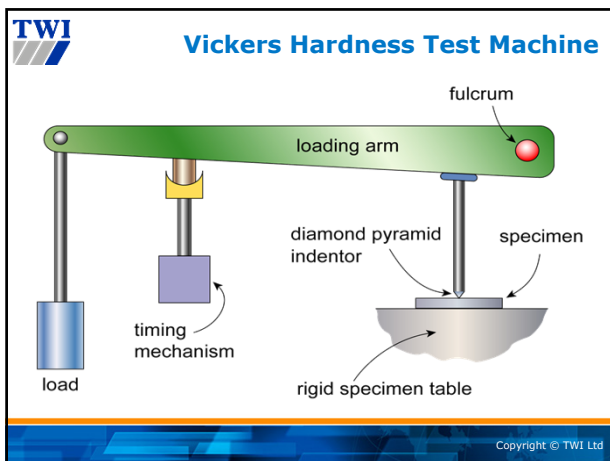


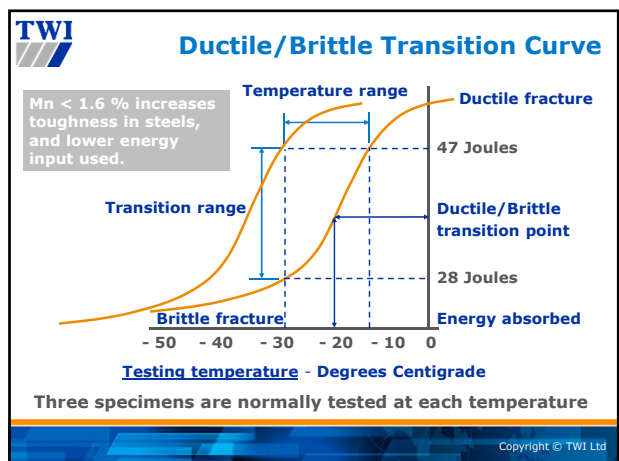
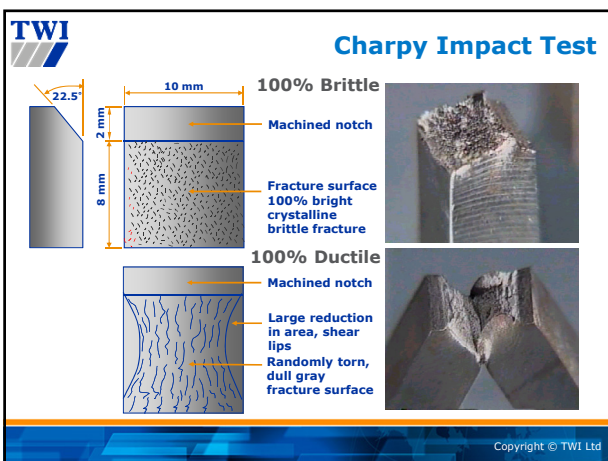
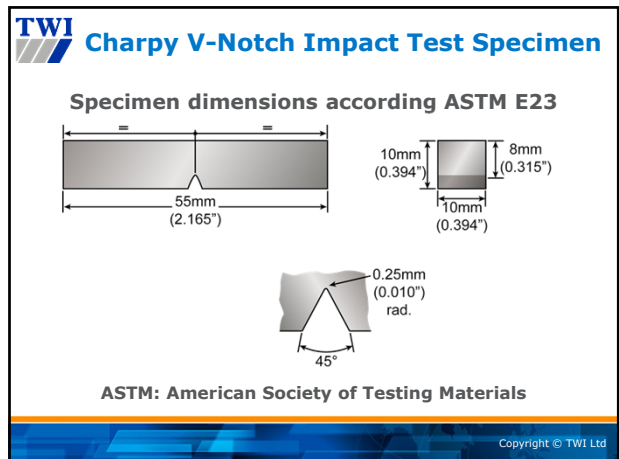
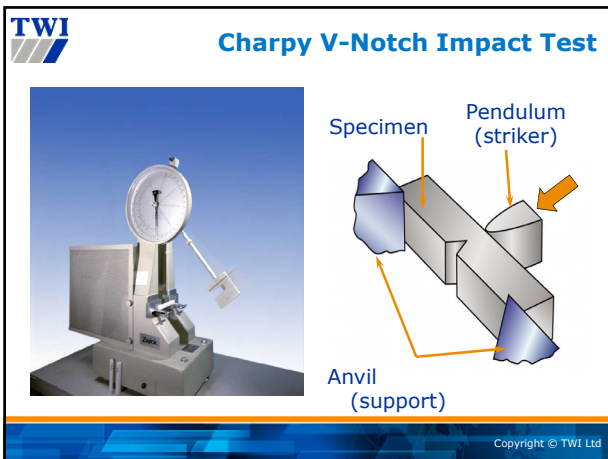
Diamond indenter

Indentation

Adjustable shutters

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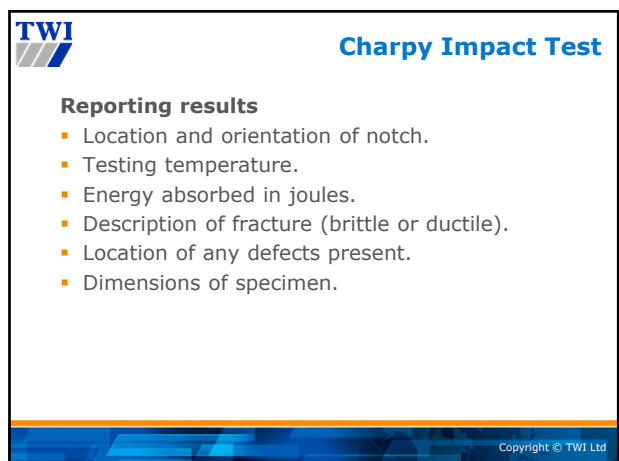
Comparison Charpy Impact Test Results

Impact Energy Joules

Room Temperature	-20°C Temperature
1. 197 Joules	1. 49 Joules
2. 191 Joules	2. 53 Joules
3. 186 Joules	3. 51 Joules
Average = 191 Joules	Average = 51 Joules

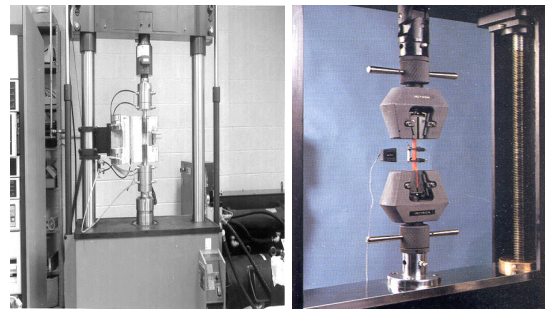
The test results show the specimens carried out at room temperature absorb more energy than the specimens carried out at -20°C.

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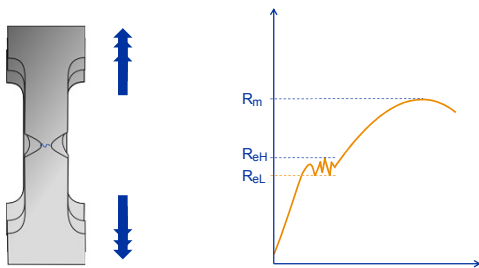


Tensile Testing

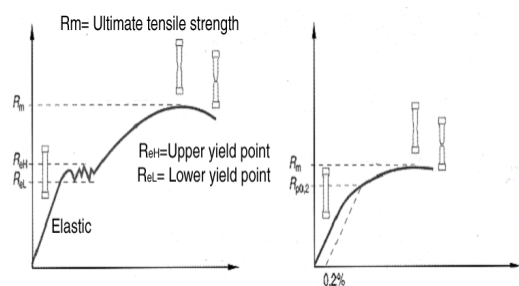
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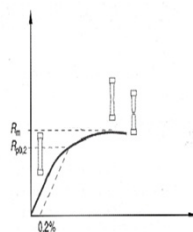
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Rp 0.2% - Proof stress

Refers to materials which do not have a defined yielding such as aluminium and some steels.

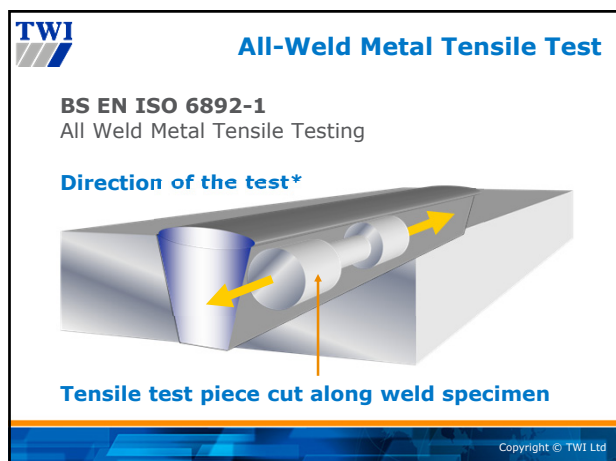
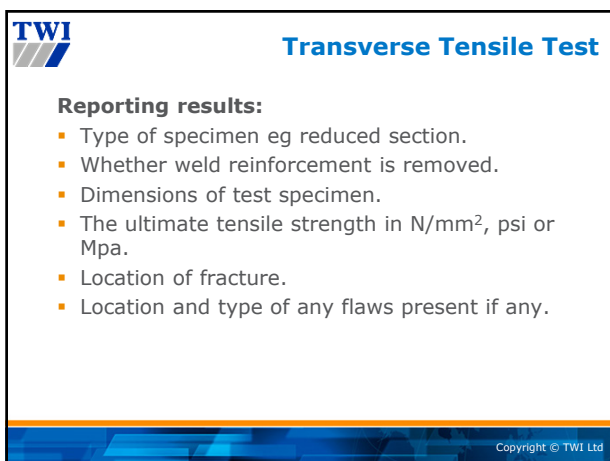
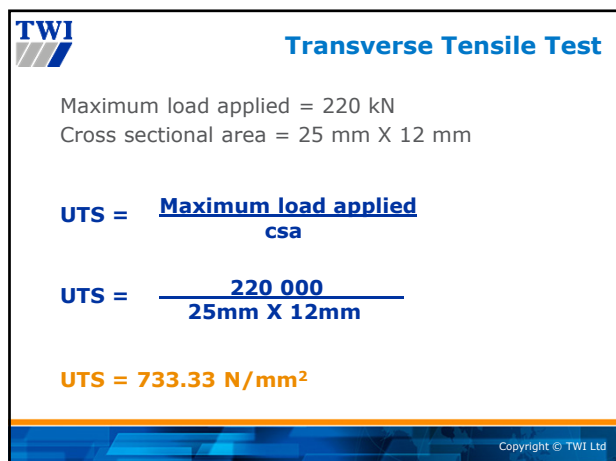
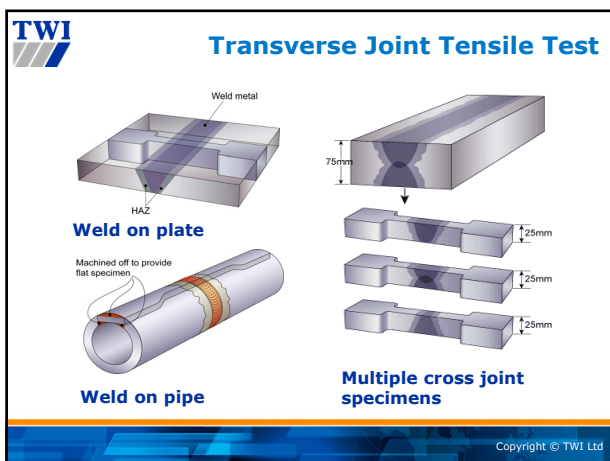
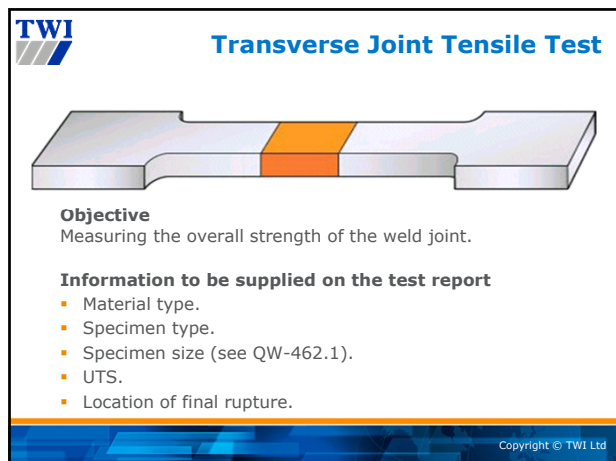
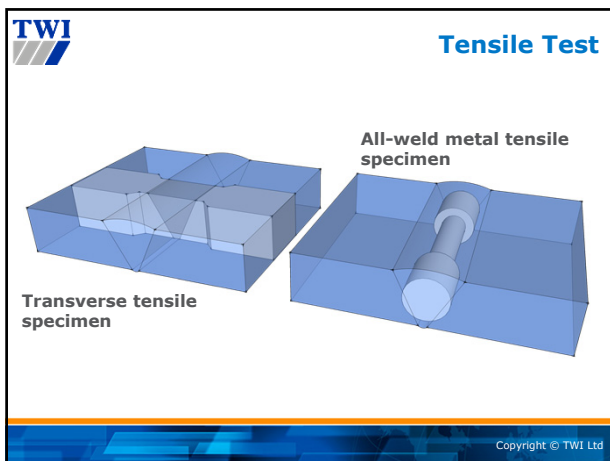


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Different tensile tests

- Transverse tensile.
- All-weld metal tensile test.
- Cruciform tensile test.
- Short tensile test (through thickness test).

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All-Weld Metal Tensile Test

Original gauge length = 50mm
Increased gauge length = 64

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

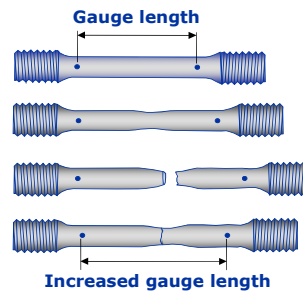
$$\text{Elongation \%} = \frac{14}{50} \times 100$$

$$\text{Elongation} = 28\%$$

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All-Weld Metal Tensile Test



Object of test

- Ultimate tensile strength.
- Yield strength.
- Elongation % (ductility).

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All-Weld Metal Tensile Test

Two marks are made
Gauge length 50mm



During the test, yield and tensile strength are recorded
The specimen is joined and the marks are re-measured



A measurement of 75mm will give Elongation of 50%

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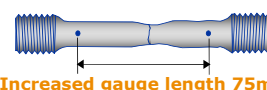


All-Weld Metal Tensile Test

Two marks are made
Gauge length 50mm



During the test, Yield & Tensile strength are recorded
The specimen is joined and the marks are re-measured



A measurement of 75mm will give Elongation of 50%

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All-Weld Metal Tensile Test

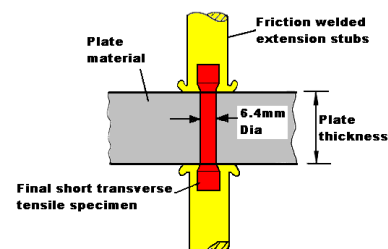
Reporting results

- Type of specimen eg reduced section.
- Dimensions of test specimen.
- The UTS, yield strength in N/mm², psi or Mpa.
- Elongation %.
- Location and type of any flaws present if any.

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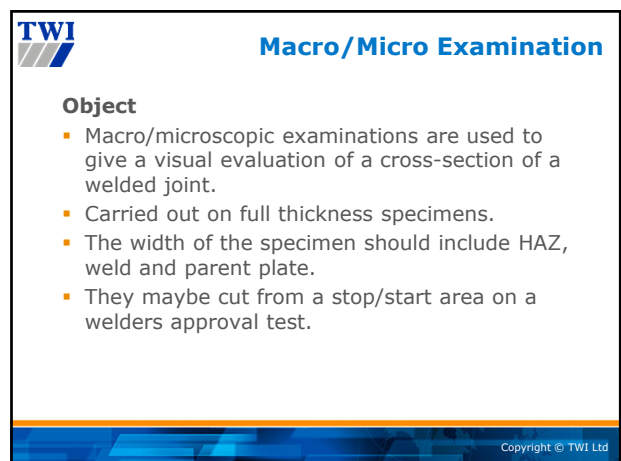
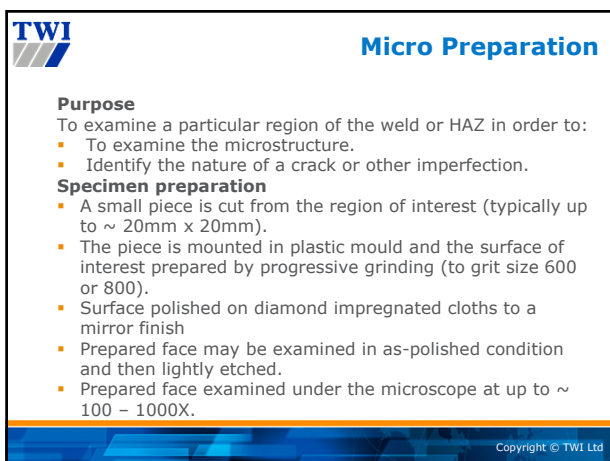
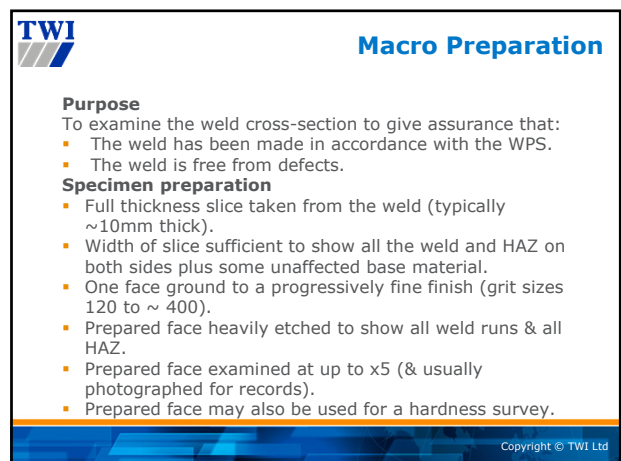
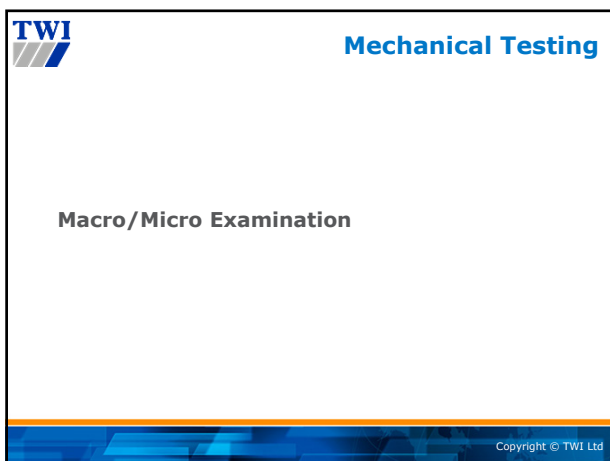
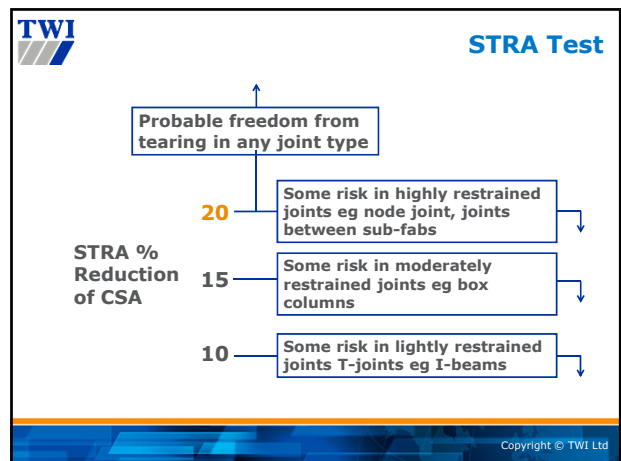
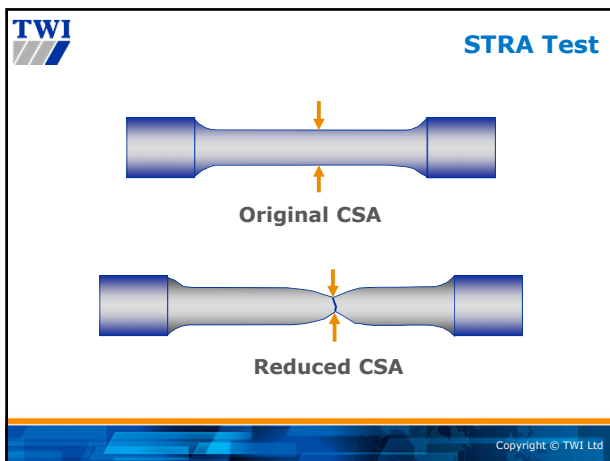


STRA (Short Transverse Reduction Area)



Short transverse tensile test specimen with friction welded extensions

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Macro/Micro Examination

Will reveal

- Weld soundness.
- Distribution of inclusions.
- Number of weld passes.
- Metallurgical structure of weld, fusion zone and HAZ.
- Location and depth of penetration of weld.
- Fillet weld leg and throat dimensions.

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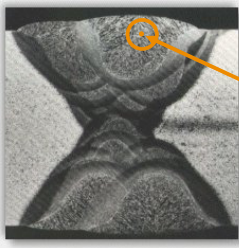
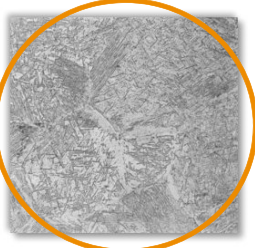
Macro/Micro Examination

Macro - Visual examination for defects. - Cut transverse from the weld. - Ground and polished P400 grit paper. - Acid etch using 5-10% nitric acid solution. - Wash and dry. - Visual evaluation under 5x magnification. - Report on results.	Micro - Visual examination for defects and grain structure. - Cut transverse from a weld. - Ground and polished P1200 grit paper, 1µm paste. - Acid etch using 1-5% nitric acid solution. - Wash and dry. - Visual evaluation under 100-1000x magnification. - Report on results.
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Metallographic Examination

Macro examination

Micro examination

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Metallographic Examination

Objectives

- Detecting weld defects (macro).
- Measuring grain size (micro).
- Detecting brittle structures, precipitates, etc.
- Assessing resistance toward brittle fracture, cold cracking and corrosion sensitivity.

Information to be supplied on the test report

- Material type.
- Etching solution.
- Magnification.
- Grain size.
- Location of examined area.
- Weld imperfections (macro).
- Phase, constituents, precipitates (micro).

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Mechanical Testing

Bend Testing

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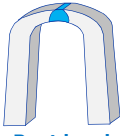
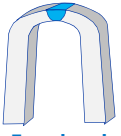
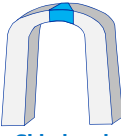
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Bend Tests

Object of test

To determine the soundness of the weld zone. Bend testing can also be used to give an assessment of weld zone ductility.

There are three ways to perform a bend test:

Root bend

Face bend

Side bend

Side bend tests are normally carried out on welds over 12mm in thickness.

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Bending Test

Types of bend test for welds
(acc BS EN ISO 5173):

Thickness of material - t

- t up to 12 mm → Root/face bend
- t over 12 mm → Side bend

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Bending Test Methods

Guided bend test

Wrap around bend test

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Bend Testing

Face bend

Side bend

Root bend

Defect indication generally this specimen would be unacceptable

Acceptance for minor ruptures on tension surface depends upon code requirements.

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Bend Tests

Reporting results

- Thickness and dimensions of specimen.
- Direction of bend (root, face or side).
- Angle of bend (90° , 120° , 180°).
- Diameter of former (typical 4T).
- Appearance of joint after bending eg type and location of any flaws.

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Mechanical Testing

Fillet Weld Fracture Testing

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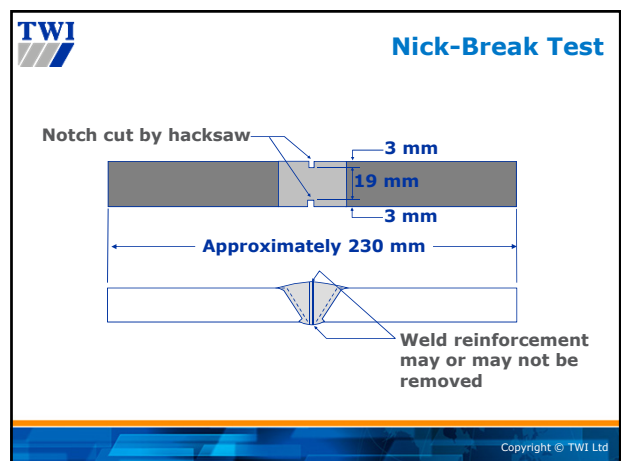
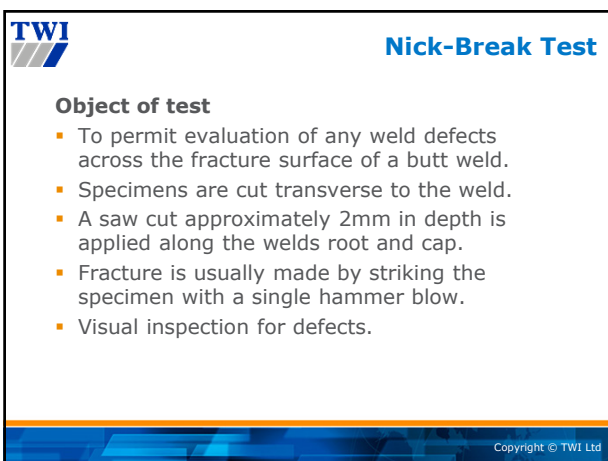
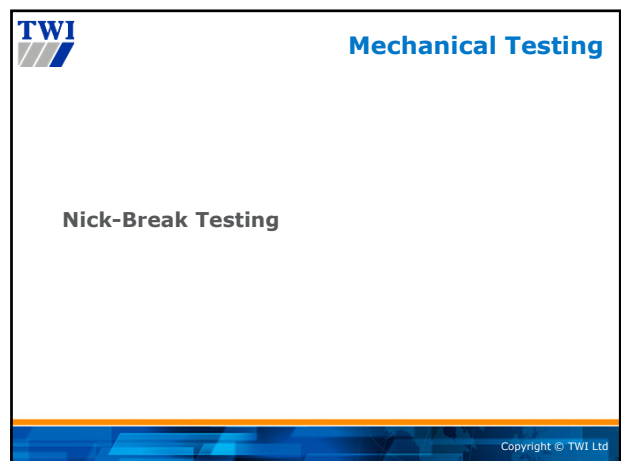
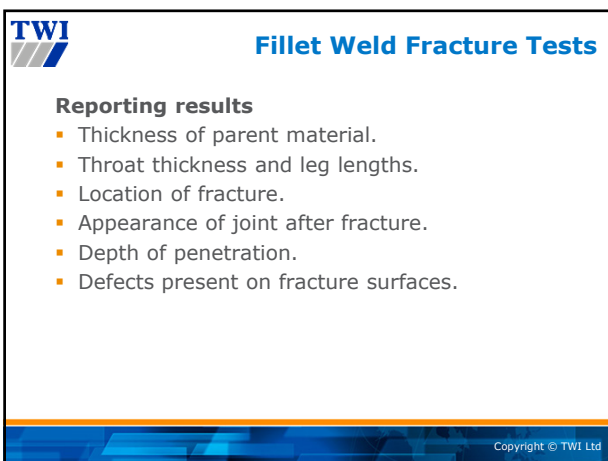
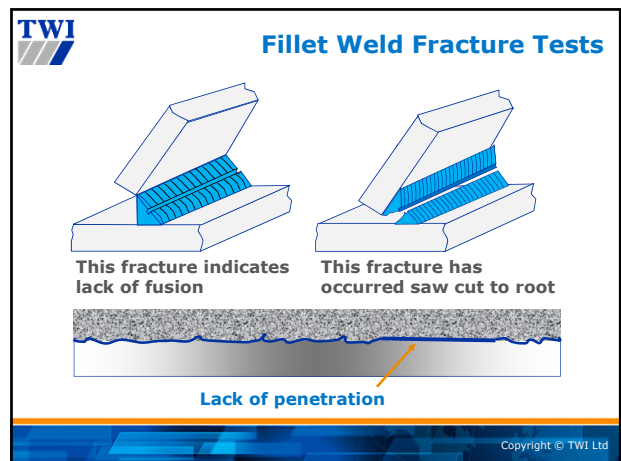
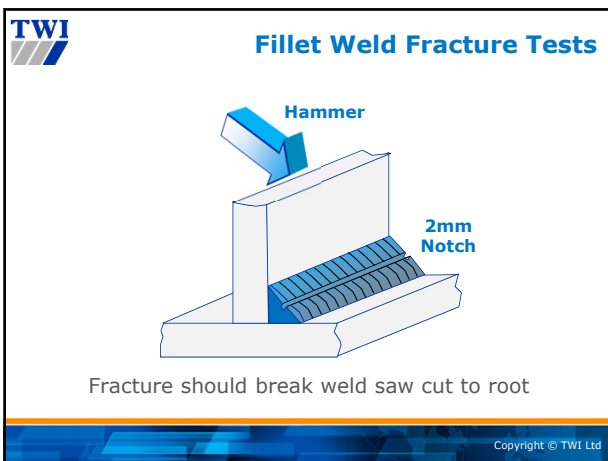
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Fillet Weld Fracture Tests

Object of test

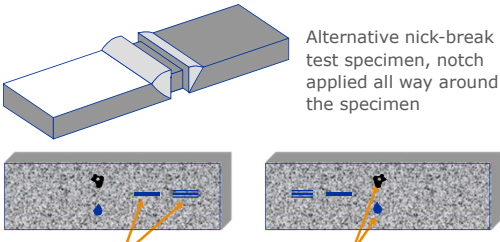
- To break open the joint through the weld to permit examination of the fracture surfaces.
- Specimens are cut to the required length.
- A saw cut approximately 2mm in depth is applied along the fillet welds length.
- Fracture is usually made by striking the specimen with a single hammer blow.
- Visual inspection for defects.

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Nick-Break Test



Alternative nick-break test specimen, notch applied all way around the specimen

Lack of root penetration or fusion

Inclusions on fracture line

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Nick-Break Test

Reporting results

- Thickness of parent material.
- Width of specimen.
- Location of fracture.
- Appearance of joint after fracture.
- Depth of penetration.
- Defects present on fracture surfaces.

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Summary of Mechanical Testing

We test welds to establish minimum levels of mechanical properties and soundness of the welded joint

We divide tests into qualitative and quantitative methods:

Quantitative: (Have units) ▪ Hardness (VPN & BHN) ▪ Toughness (Joules & ft.lbs) ▪ Strength (N/mm² & PSI, MPa) ▪ Ductility/Elongation (E%)	Qualitative: (Have no units) ▪ Macro tests ▪ Bend tests ▪ Fillet weld fracture tests ▪ Butt nick-break tests
--	--

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Hydrostatic Test

Under pressure leakage proof test

Vessel configuration

- The test should be done after any stress relief.
- Components that will not stand the pressure test (eg flexible pipes, diaphragms) must be removed.
- The ambient temperature MUST be above 0°C (preferably 15-20°C).

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Hydrostatic Test

Test procedure

- Blank off all openings with solid flanges.
- Use correct nuts and bolts, **not** G clamps.
- Two pressure gauges on independent tapping points should be used.
- For safety purposes bleed all the air out.
- Pumping should be done slowly (no dynamic pressure stresses).
- Test pressure - see relevant standards (PD 5500, ASME VIII). Usually 150% design pressure.
- Hold the pressure for minimum 30 minutes.

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Hydrostatic Test

What to look for

- Leaks (check particularly around seams and nozzle welds)!
- Dry off any condensation.
- Watch the gauges for pressure drop.
- Check for distortion of flange faces, etc.

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Mechanical Testing

Any Questions



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Mechanical Testing

As part of your remit as a Senior Welding Inspector, visits to the test house are common, witnessing mechanical testing of weld procedures and welder qualifications in C Mn steel.

In addition, verifying the accompanying documentation is also a major part of your role.

Therefore, your knowledge of the TWI specification and the use of it is essential to your role.

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Question 1

You notice at the test house that root and face bends are being conducted with a 50% reduction in the former diameter than that stated in the specification. What difference would this make to the testing conditions?

- a. This should make no difference as long as the bend is to the correct angle
- b. This is common practice when reinforcement is left in place
- c. This would put excessive stress on the specimen
- d. No options are correct

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Question 2

Continuing with the witnessing of bend testing, you notice that the excess weld metal has not been removed. Are there any consequences attached to this practice?

- a. When bends are tested in this manner, the test is much more accurate as all the weld is under test
- b. The excess weld metal is only removed if it is excessive
- c. The excess weld metal could give rise to stresses
- d. Only the part in contact with the former requires the excess weld metal to be removed

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Question 3

Testing has just been completed on a single sided butt weld procedure, 10mm thick, PA position using the MMA process. Which mechanical tests would you expect to find within the documentation?

- a. 1 transverse tensile, two transverse side bends, impact tests 1 set of 3, Hardness test one specimen and macro examination
- b. 2 transverse tensile, two transverse bends-1root and 1 face bends, impact tests 1 set of 3, Hardness test one specimen and macro examination
- c. 2 transverse tensile, two transverse root and 1 face bends, hardness test one specimen and macro examination
- d. 2 transverse tensile, two transverse side bends, impact tests 1 set of 3, Hardness test one specimen and macro examination

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Question 4

You are checking the test report for a transverse tensile test on a 16mm butt weld with a UTS value of 460N/mm². Which of the following sets of tensile samples would fail the test?

- a. Test 1 failed in parent metal at 414 N/mm², test 2 failed in weld metal at 555N/mm²
- b. Test 1 failed in parent metal at 420 N/mm², test 2 failed in weld metal at 480N/mm²
- c. Test 1 failed in parent metal at 435 N/mm², test 2 failed in weld metal at 498N/mm²
- d. Test 2 failed in weld metal at 498N/mm², test 1 failed in parent metal at 435 N/mm²

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Question 5

Charpy impact tests have been conducted on a 16mm single V butt joint. Which of the following set of results would meet the specification?

- a. Average of set 30 joules, lowest individual value 20 joules
- b. Average of set 40 joules, lowest individual value 32 joules
- c. Average of set 38 joules, lowest individual value 35 joules
- d. Average of set 42 joules, lowest individual value 28 joules

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Question 6

A welder qualifies in C Mn steel, 10mm thick, MMA process using low hydrogen electrodes, PC position using DC- polarity. Which one of the following is the welder not qualified for?

- a. C mn steel, 20mm thick, MMA process, rutile electrode, PB position, DC-
- b. C mn steel, 6mm thick, MMA process, rutile electrode, PA position, DC-
- c. C mn steel, 15mm thick, MMA process, low hydrogen electrode, PC position, DC-
- d. C mn steel, 15mm thick, MMA process, rutile electrode, PE position, DC-

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Question 7

A charpy impact test is devised to test samples at different temperatures. What does this hope to establish?

- a. A transition range from ductile to brittle
- b. The Rm of the material
- c. The Re of the material
- d. The relationship between hardness and tensile strength

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Question 8

The point at which the Rm is reached in a tensile test is also referred to as the:

- a. Yield point
- b. UTS
- c. A%
- d. Gauge length

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Question 9

If a tensile test specimen fails to meet the required value, what action can be taken?

- a. Two more test welds are required which will require complete testing
- b. One more test sample can be submitted
- c. If the specimen is large enough, two more tests can be done
- d. As many test welds as required can be submitted until the tests meet the specification

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Question 10

In a procedure qualification in 10m thick material welded in the PF position when impacts are not specified, which position(s) is the procedure qualified for?

- a. PA, PC
- b. PF, PG
- c. All positions
- d. PF only

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Section 7

Heat Treatment

7 Heat Treatment

The heat treatment given to a particular grade of steel by the steelmaker/supplier should be shown on the material test certificate and may be referred to as the supply condition.

Welding inspectors may need to refer to material test certificates and it is appropriate that they be familiar with the terminology that is used and have some understanding of the principles of some of the most commonly applied heat treatments.

Welded joints may need to be subjected to heat treatment after welding (PWHT) and the tasks of monitoring the thermal cycle and checking the heat treatment records are often delegated to welding inspectors.

7.1 Heat treatment of steel

The main supply conditions for weldable steels are:

As rolled, hot rolled, hot finished

Plate is hot rolled to finished size and allowed to air cool; the temperature at which rolling finishes may vary from plate to plate and so strength and toughness properties vary and are not optimised:

Applied to:

Relatively thin, lower strength C-steel.

Thermo-mechanical controlled processing (TMCP), control rolled, thermo-mechanically rolled

Steel plate given precisely controlled thickness reductions during hot rolling within carefully controlled temperature ranges; final rolling temperature is also carefully controlled;

Applied to

Relatively thin, high strength low alloy steels (HSLA) and for some steels with good toughness at low temperatures, eg cryogenic steels.

Normalised

After working the steel (rolling or forging) to size, it is heated to ~900°C and then allowed to cool in air to ambient temperature; this optimises strength and toughness and gives uniform properties from item to item for a particular grade of steel;

Applied to

C-Mn steels and some low alloy steels.

Quenched and tempered

after working the steel (rolling or forging) to size, it is heated to ~900°C and then cooled as quickly as possible by quenching in water or oil; after quenching, the steel must be tempered (softened) to improve the ductility of the as-quenched steel:

Applied to

Some low alloy steels to give higher strength, toughness or wear resistance.

Solution annealed / heat treated

After hot or cold working to size, steel heated to ~1100°C and rapidly cooled by quenching into water to prevent any carbides or other phases from forming:

Applied to

Austenitic stainless steels such as 304 and 316 grades.

Annealed

After working the steel (pressing or forging etc) to size, it is heated to ~900°C and then allowed to cool in the furnace to ambient temperature; this reduces strength and toughness but improves ductility:

Applied to

C-Mn steels and some low alloy steels.

Figure 7.1-7.6 show the thermal cycles for the main supply conditions and subsequent heat treatment that can be applied to steels.

7.2 Post weld heat treatment (PWHT)

Post weld heat treatment has to be applied to some welded steels to ensure that the properties of the weldment will be suitable for their intended applications.

The temperature at which PWHT is carried out is usually well below the temperature where phase changes can occur (note 1), but high enough to allow residual stresses to be relieved quickly and to soften (temper) any hard regions in the HAZ.

There are major benefits of reducing residual stress and ensuring that the HAZ hardness is not too high for particular steels with certain service applications.

Examples of these benefits are:

- Improved the resistance of the joint to brittle fracture.
- Improved the resistance of the joint to stress corrosion cracking.
- Enables welded joints to be machined to accurate dimensional tolerances.

Because the main reason for (and benefit of) PWHT is to reduce residual stresses, PWHT is often called **stress relief**.

Note: There are circumstances when a welded joint may need to be normalised to restore HAZ toughness. However, these are relatively rare circumstances and it is necessary to ensure that welding consumables are carefully selected because normalising will significantly reduce weld metal strength.

7.3 PWHT thermal cycle

The application standard/code will specify when PWHT is required to give benefits #1 or #2 above and also give guidance about the thermal cycle that must be used.

In order to ensure that a PWHT cycle is carried out in accordance with a particular code, it is essential that a PWHT procedure is prepared and that the following parameters are specified:

- Maximum heating rate.
- Soak temperature range.
- Minimum time at the soak temperature (soak time).
- Maximum cooling rate.

7.3.1 Heating rate

This must be controlled to avoid large temperature differences within the fabricated item. Large differences in temperature (large thermal gradients) will produce large stresses and these may be high enough to cause distortion (or even cracking).

Application standards usually require control of the maximum heating rate when the temperature of the item is above $\sim 300^{\circ}\text{C}$. This is because steels start to show significant loss of strength above this temperature and are more susceptible to distortion if there are large thermal gradients.

The temperature of the fabricated item must be monitored during the thermal cycle and this is done by means of thermocouples attached to the surface at a number of locations representing the thickness range of the item.

By monitoring furnace and item temperatures the rate of heating can be controlled to ensure compliance with code requirements **at all positions within the item**.

Maximum heating rates specified for C-Mn steel depend on thickness of the item but tend to be in the range ~ 60 to $\sim 200^{\circ}\text{C/h}$.

7.3.2 Soak temperature

The soak temperature specified by the code depends on the type of steel and thus the temperature range required to reduce residual stresses to a low level.

C and C-Mn steels require a soak temperature of $\sim 600^{\circ}\text{C}$ whereas some low alloy steels (such as Cr-Mo steels used for elevated temperature service) require higher temperatures – typically in the range ~ 700 to $\sim 760^{\circ}\text{C}$.

Note: Soak temperature is an essential variable for a WPQR. Thus, it is very important that it is controlled within the specified limits otherwise it may be necessary to carry out a new WPQ test to validate the properties of the item and at worst it may not be fit-for-purpose.

7.3.3 Soak time

It is necessary to allow time for all the welded joints to experience the specified temperature throughout the full joint thickness.

The temperature is monitored by surface-contact thermocouples and it is the thickest joint of the fabrication that governs the minimum time for temperature equalisation.

Typical specified soak times are 1h per 25mm thickness.

7.3.4 Cooling rate

It is necessary to control the rate of cooling from the PWHT temperature for the same reason that heating rate needs to be controlled – to avoid distortion (or cracking) due to high stresses from thermal gradients.

Codes usually specify controlled cooling to ~300°C. Below this temperature the item can be withdrawn from a furnace and allowed to cool in air because steel is relatively strong and is unlikely to suffer plastic strain by any temperature gradients that may develop.

Figure 7.6 is a typical PWHT thermal cycle.

7.4 Heat treatment furnaces

It is important that oil and gas-fired furnaces used for PWHT do not allow flame contact with the fabrication as this may induce large thermal gradients.

It is also important to ensure that the fuel (particularly for oil-fired furnaces) does not contain high levels of potentially harmful impurities – such as sulphur.

7.5 Local PWHT

For a pipeline or pipe spool it is often necessary to apply PWHT to individual welds by local application of heat.

For this, a PWHT procedure must specify the previously described parameters for controlling the thermal cycle but it is also necessary to specify the following:

- Width of the heated band (must be within the soak temperature range).
- Width of the temperature decay band (soak temperature to ~300°C).

Other considerations are:

- Position of the thermocouples within the heated band width and the decay band.
- If the item needs to be supported in a particular way to allow movement/avoid distortion.

The commonest method of heating for local PWHT is by means of insulated electrical elements (electrical 'mats') that are attached to the weld.

Gas-fired, radiant heating elements can also be used.

Figure 7.7 shows typical control zones for localised PWHT of a pipe butt weld.

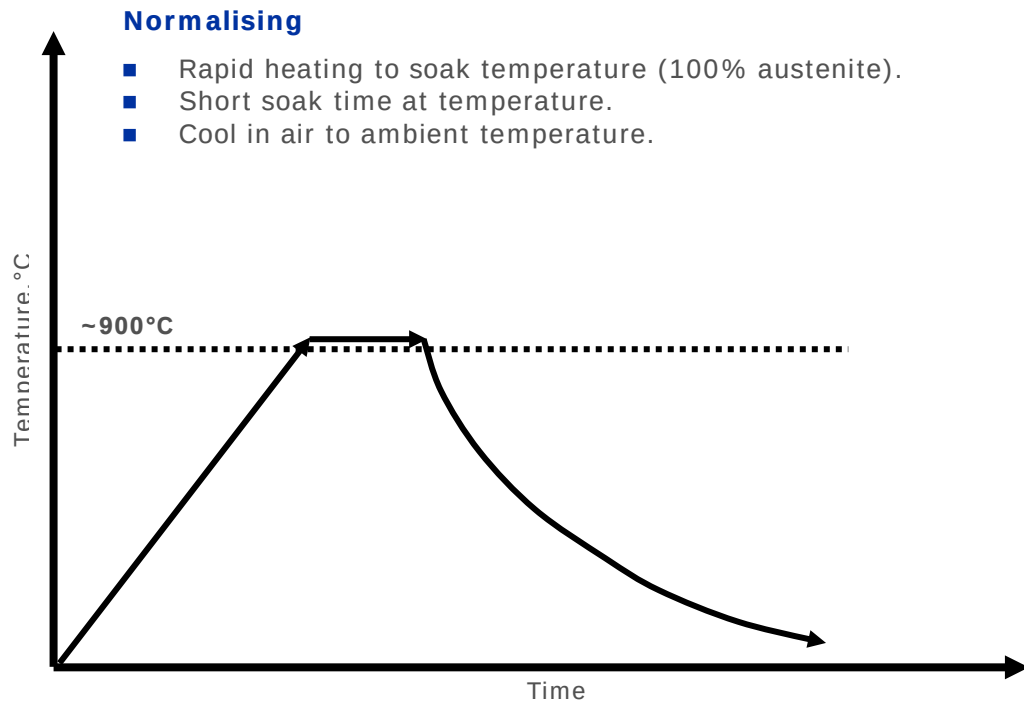


Figure 7.1 Typical normalising heat treatment applied to C-Mn and some low alloy steels.

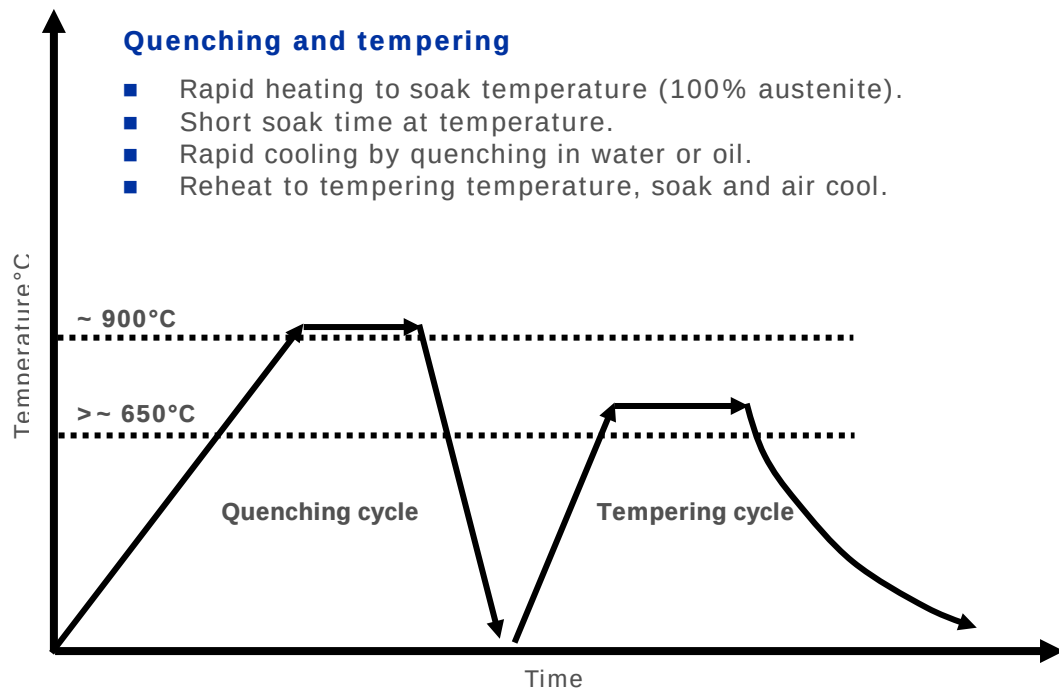


Figure 7.2 Typical quenching and tempering heat treatment applied to some low alloy steels.

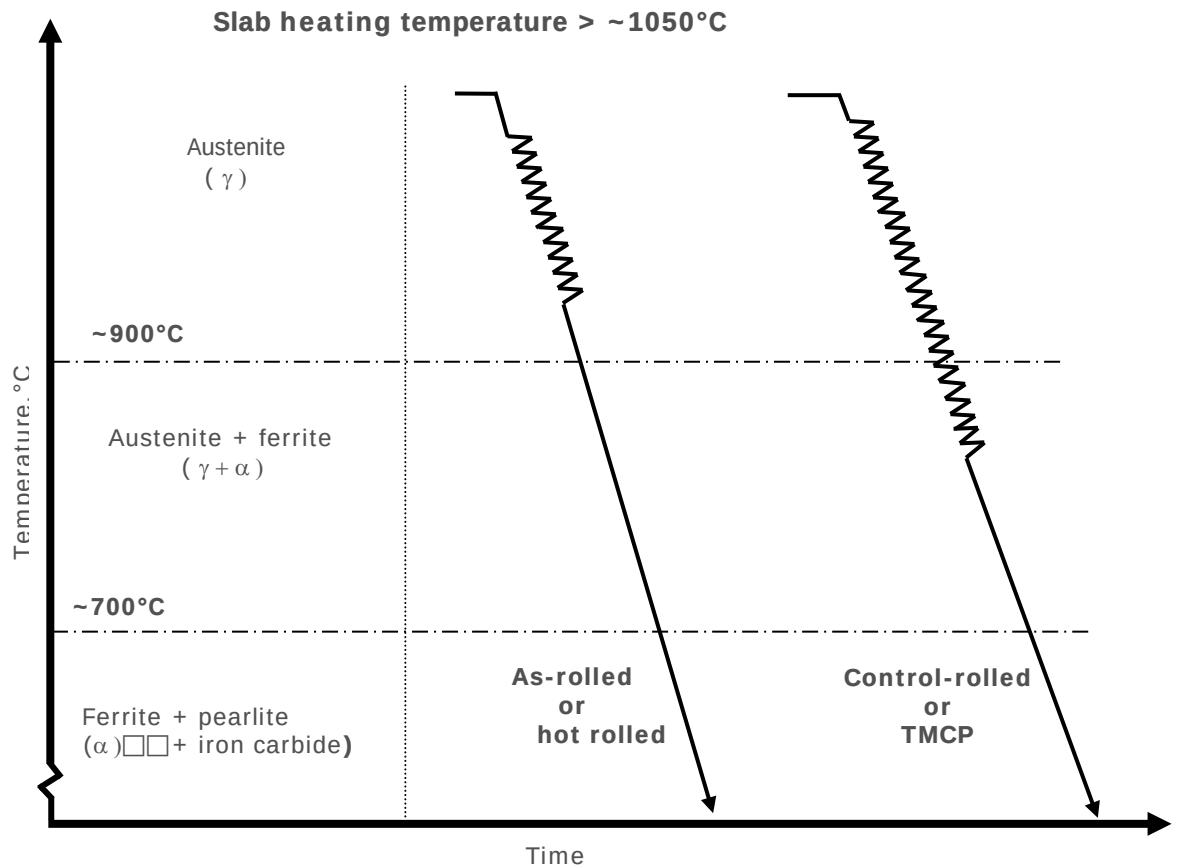


Figure 7.3 Comparison of the 'control-rolled' (TMCP) and 'as-rolled' conditions (= hot rolling).

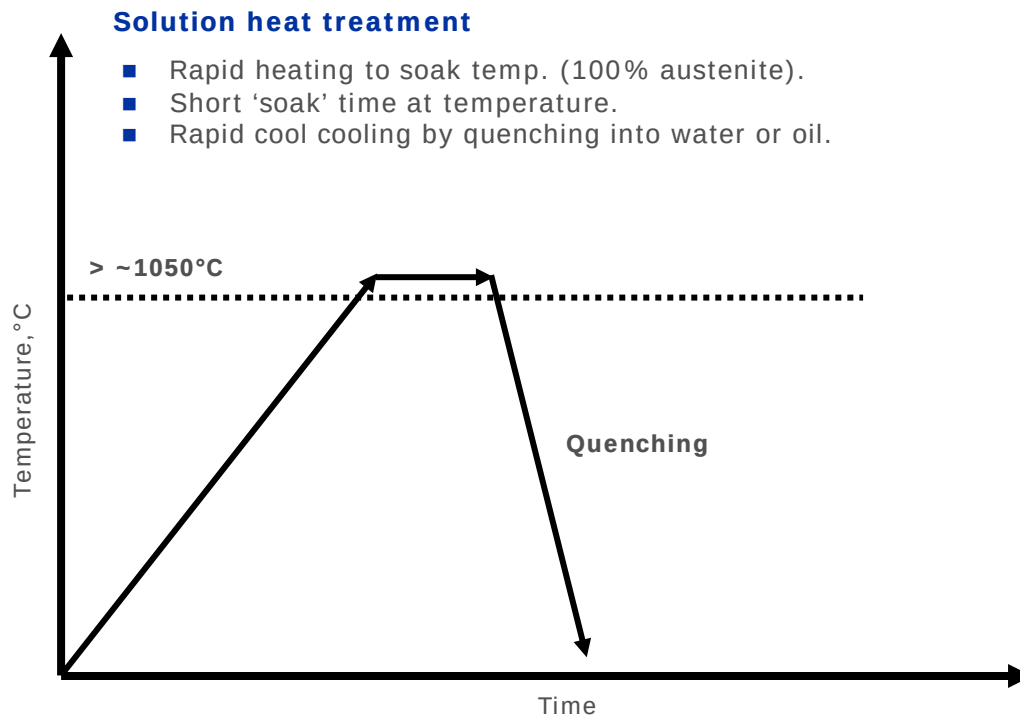


Figure 7.4 Typical solution heat treatment (solution annealing) applied to austenitic stainless steels.

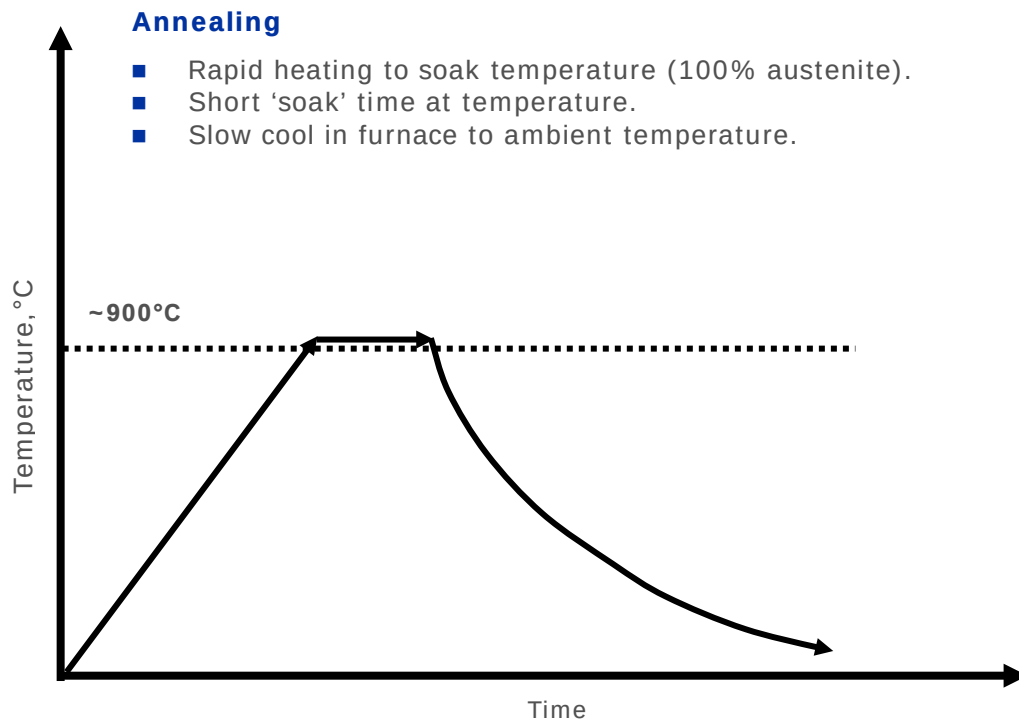


Figure 7.5 Typical annealing heat treatment applied to C-Mn and some low alloy steels.

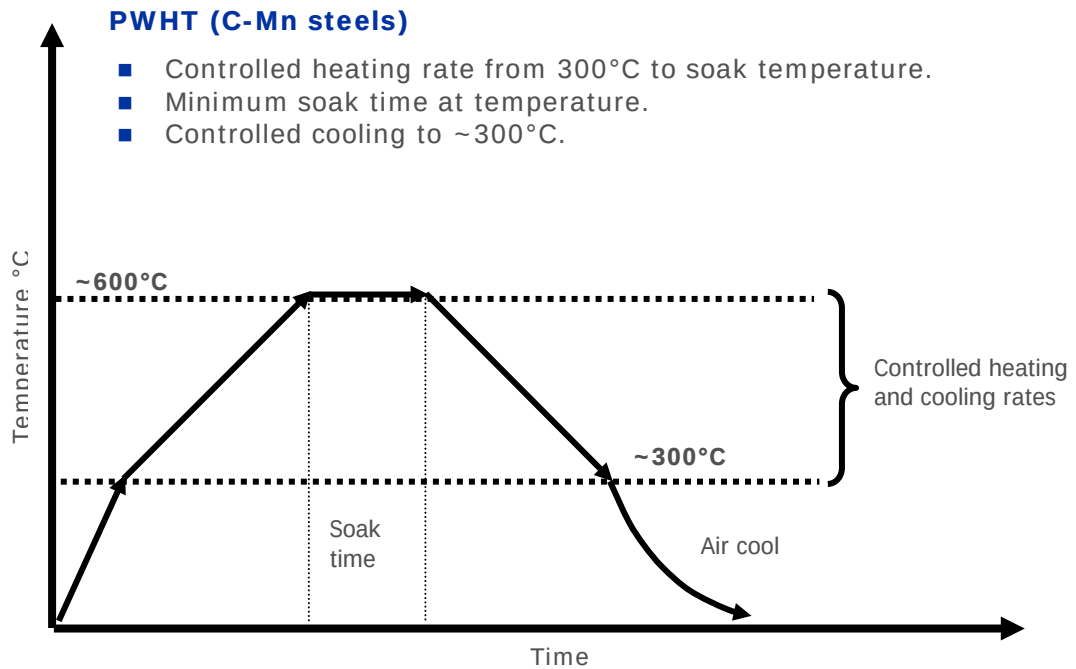


Figure 7.6 Typical PWHT applied to C-Mn steels.

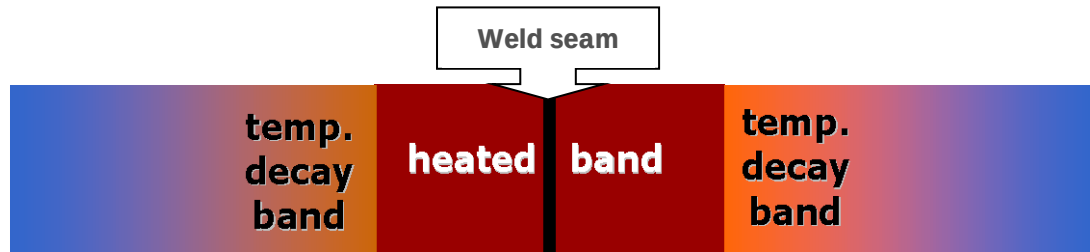
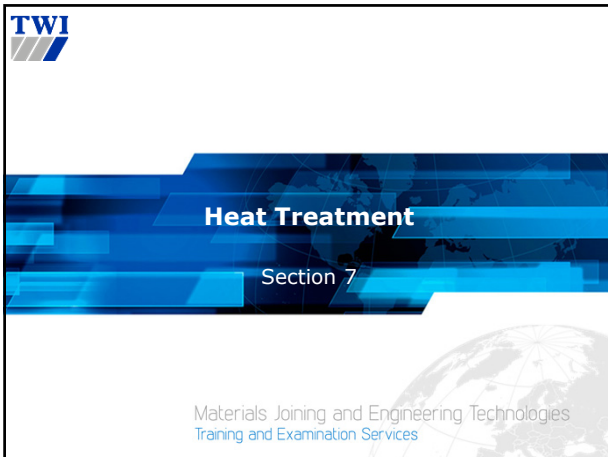


Figure 7.7 Local PWHT of a pipe girth seam.



Heat Treatment

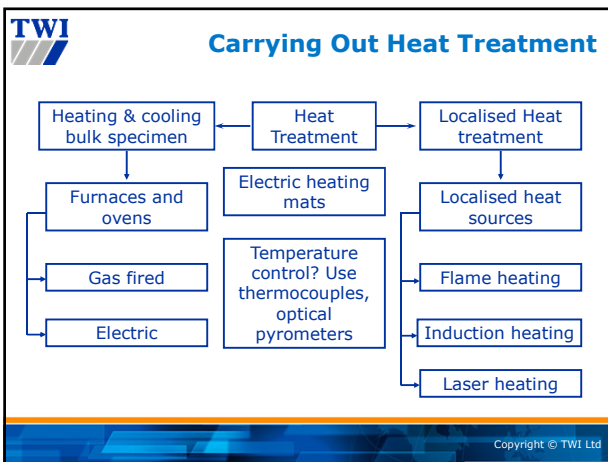
Controlled heating and cooling to bring about desired changes in metals and alloys

Objectives

- Microstructural changes improve mechanical properties ie toughness, machinability, strength.
- Reduce residual stress level.

Global ← Where? → Local

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Heat Treatment Equipment

Furnaces and ovens

Gas fired:

- Special attention to environment control.
- Heat from oxygen + fuel gas (methane, propane).
- High concentration of oxygen may result in scaling, a neutral environment is beneficial.
- Avoid heat gradients.
- Radiant tube furnaces to avoid contact with combustion product.

Electric furnaces:

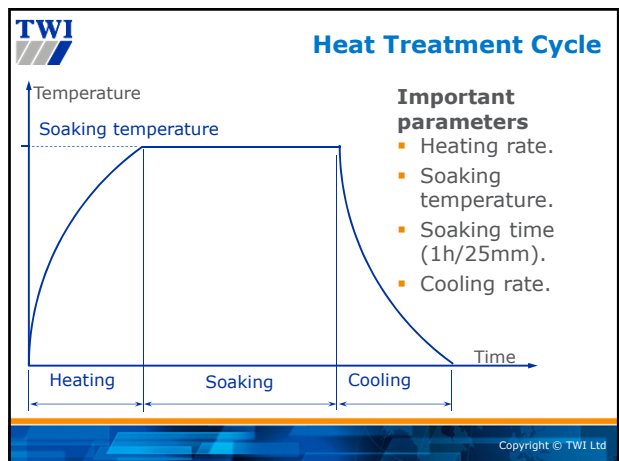
- Cleaner environment.
- Expensive.

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Localised Heat Treatment

- Heating and cooling a specific portion of a component, ie gear edge, case or surface hardening, weld PWHT.
- Gas flames such as oxygen + methane or propane.
- Induction.
- Electric heating blankets.

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Types of Heat Treatment

- Annealing.
- Normalising.
- Recovery and re-crystallisation.
- Stress relief.
- Quenching and tempering.
- Precipitation hardening.

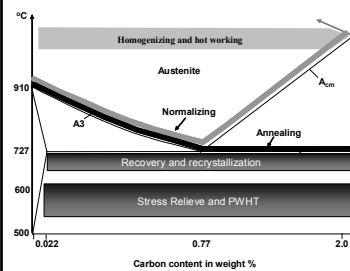
Welds & parent metals

Parent metals

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Heat Treatment Temperatures



Annealing

Normalising

Recovery & re-crystallisation
Stress relief & PWHT

Phase change to austenite

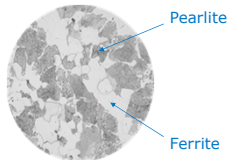
No phase change

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Full Annealing - Steel

- Heated to high temperature (Partially or fully austenitic):
 - Hypereutectic steels are partially austenitized to avoid cementite formation on grain boundaries during slow cooling.
- Hold for some time and then slow cool.
- Coarse grain size.
- Reduced strength.
- Increased ductility.
- Homogeneous.

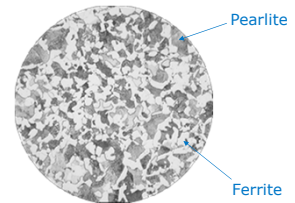


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Normalising

- Steel heated just to where austenite is stable.
- Air cooling – fairly rapid.
- Grain refinement.
- Stress relief.
- Higher strength.
- Higher toughness.



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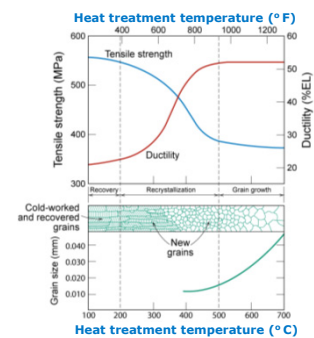
Recovery and Re-crystallisation

- Cold work increases strength and reduces ductility and toughness.
- Reversed by recovery and re-crystallisation:
 - But if temperature too high excessive grain growth leads to drop in strength and toughness.
- Recovery reduces the stored energy in cold-worked or deformed (rolled) material.
- Dislocations move and align at heat treatment temperature (recovery).
- New defect-free grains nucleate from grain boundaries and grow (recrystallisation).

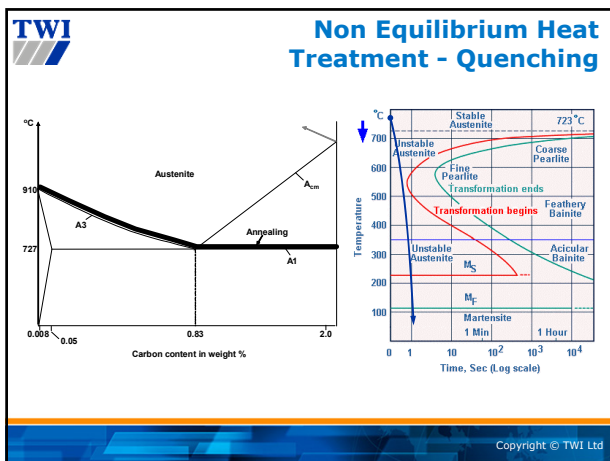
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Recovery and Recrystallisation



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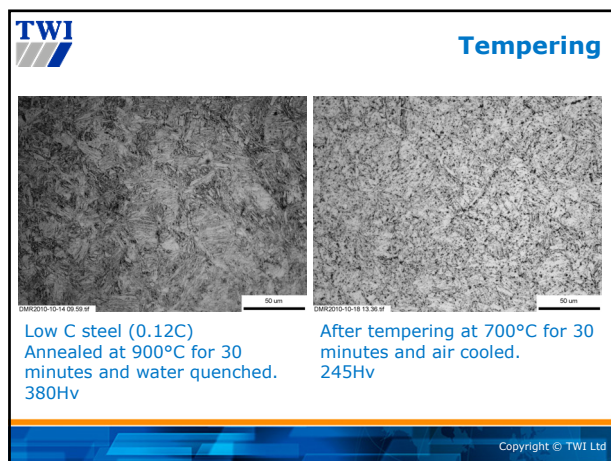
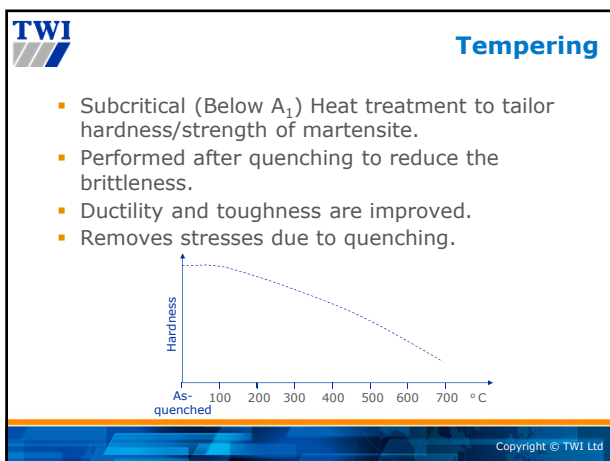


Non Equilibrium Heat Treatment - Quenching

- Heating to annealing heat treatment temperature range.
- Fast cooling to increase hardness:
 - Brine (Water and salt).
 - Water.
 - Oil.
- Ductility and toughness are drastically reduced.
- Usually followed by tempering.

Increased quench severity

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Heat Treatments Following Welding

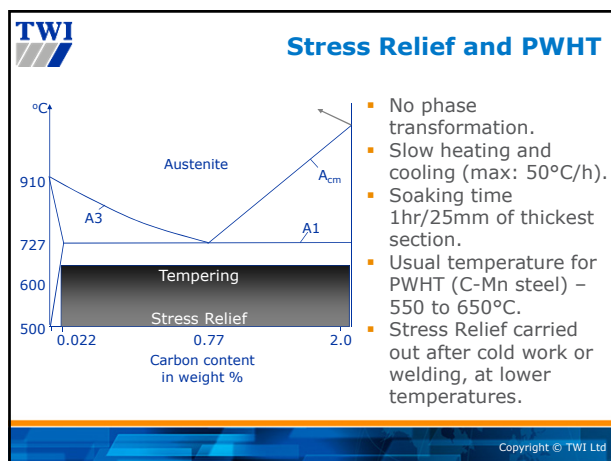
Stress relief

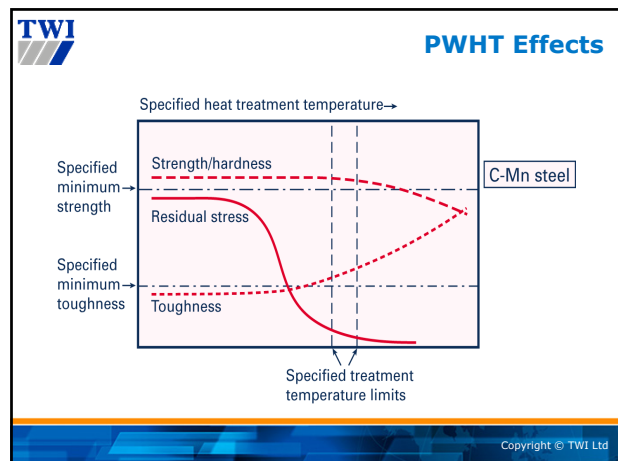
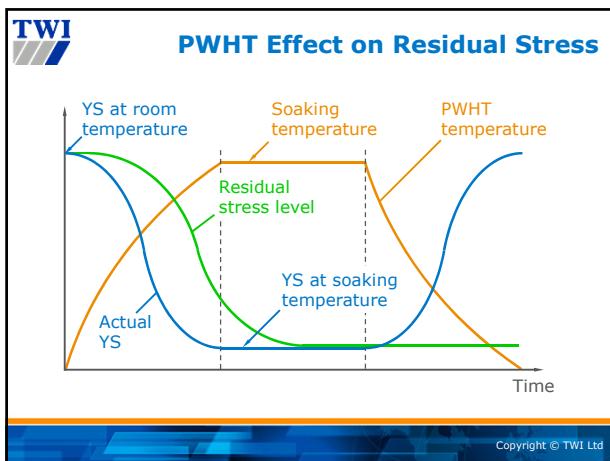
- Carried out at lower temperature, to reduce residual stresses.

Tempering

- Carried out at higher temperature (for constructional steels).
- Not only relieves stresses but also softens the hard HAZ microstructure.

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- TWI** **PWHT Recommendations**
- Provide adequate support (low YS at high temperature!).
 - Control heating rate to avoid uneven thermal expansions.
 - Control soak time to equalise temperatures.
 - Control temperature gradients - No direct flame impingement.
 - Control furnace atmosphere to reduce scaling.
 - Control cooling rate to avoid new residual stresses.
 - For specific PWHT applications see standards, eg ASME VIII, ASME B31.3, ASME B31.8.
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TWI **Heat Treatments**

You are assigned to a heat treatment company to witness heat treatments being conducted.

The heat treatments are being conducted on various products for a major offshore oil and gas project that you have been involved with.

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TWI **Question 1**

While inspecting some cast duplex valve bodies one of your inspectors asks if the castings require a heat treatment process. Which of the following would most likely be applied to these items?

- Solution annealing
- Quench hardening
- No heat treatment required
- Stress relieving would be required but only after welding if applicable

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TWI **Question 2**

A set of fabricated brackets manufactured from 316L stainless steel is about to be heat-treated, which of the following applies?

- This material is always stress relieved after welding
- A post weld heat treat isn't generally conducted on this type of material
- Quench hardening would always be applied to this material to increase toughness after welding
- All options are incorrect

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Question 3

During the post weld heat treatment of a small welded fabrication, you observe the heat treatment personnel applying heat by a heating torch. In accordance with TWI Specification do you consider this an acceptable practice?

- a. Yes this is acceptable providing the temperature attained and the soaking times are correct in accordance with the approved PWHT procedure
- b. Yes this is acceptable providing the thermocouples are correctly placed and calibrated
- c. No, this application method isn't acceptable
- d. 2 options are correct

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Question 4

Unfortunately the stress relieving of a welded fabricated steel structure hasn't been witnessed by any of your inspectors. When you review the PWHT chart you notice only 2 thermocouples have been used. In accordance with the TWI Specification do you consider this to be acceptable?

- a. No, all PWHT shall be witnessed and a minimum of 3 thermocouples shall be used
- b. Yes, only the PWHT charts require reviewing by inspectors
- c. No, all PWHT shall be witnessed, an inspector has to be present 100% of the time throughout the PWHT process
- d. No, a minimum of 3 thermocouples shall be used, and calibration certificates require checking prior to the heat treatment process

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Question 5

It is a requirement for a quenched and tempered component to undergo post weld heat treatment, one of your inspectors asks you what is the maximum temperature required for this material. Which of the following is correct in accordance the TWI Specification?

- a. The same as for C/Mn steel
- b. You would never permit a PWHT to be carried out on this material
- c. The TWI Specification doesn't reference this information, but would expect it to be around 680°C
- d. All options are incorrect

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Question 6

During Post Weld Heat Treatment, what sequence of events occurs to the properties of the material?

- a. Yield strength increases, stresses decrease then yield strength decreases
- b. Ductility decreases, stresses increase then ductility increases
- c. Yield strength decreases, stresses decrease then yield strength increases
- d. Stresses increase, stresses decrease then yield increases

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Question 7

After a PWHT process has been carried out on some thick to thin C/Mn pipe spools (12.5mm to 25mm WT) you notice that the heating rate is recorded at 200°C/Hr. In accordance with the TWI Specification is this correct?

- a. No, it should be a minimum of 220°C/hr
- b. No, it should be 40°C/hr
- c. Yes, Providing the cooling rate is the same
- d. Yes, providing the cooling rate is 220°C/hr

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Question 8

While reviewing the heat treatment chart for a PWHT process you notice that the temperature is not recorded below 150°C on the cooling cycle. Would you accept this chart?

- a. No, the temperature must be recorded down to room temperature
- b. It would depend on the thickness and grade of material as to whether this would be acceptable or not
- c. No, the temperature has to be recorded to at least 110°C
- d. The TWI Specification doesn't reference this information.

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Question 9

In certain cases heat treatments are conducted on cold work components such as cold rolled, steel plate. Which of the following heat treatments would you expect to be conducted on these components?

- a. Stress relieving
- b. Densensitization
- c. Quench hardening
- d. Post hydrogen release

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Question 10

You notice from your records you don't have an inspection report for a component that has undergone a PWHT. In this case what would your course of action be?

- a. It would be acceptable, If the component had a full inspection report before PWHT
- b. The TWI Specification makes no reference of this, so you would have to seek advice
- c. It is a requirement that all components undergo full inspection after a PWHT process has been conducted; in this case it would not be acceptable
- d. As long as no welding has be conducted after the PWHT process, this would be acceptable

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Section 8

WPS and Welder Qualifications

8 WPS and Welder Qualifications

When structures and pressurised items are fabricated by welding, it is essential that all the welded joints are sound and have suitable properties for their application.

Control of welding is by means of welding procedure specifications (WPS) that give detailed written instructions about the welding conditions that must be used to ensure that welded joints have the required properties.

Although WPS are shop floor documents to instruct welders, welding inspectors need to be familiar with them because they will need to refer to WPSs when they are checking that welders are working in accordance with the specified requirements.

Welders need to understand WPSs and have the skill to make welds that are not defective and demonstrate these abilities before being allowed to make production welds.

8.1 Qualified welding procedure specifications

It is industry practice to use **qualified WPS** for most applications.

A welding procedure is **usually qualified** by making a test weld to demonstrate that the properties of the joint satisfy the requirements specified by the application standard (and the client/end user).

Demonstrating the mechanical properties of the joint is the principal purpose of qualification tests but showing that a defect-free weld can be produced is also very important.

Production welds that are made in accordance with welding conditions similar to those used for a test weld should have similar properties and therefore be fit for their intended purpose.

Figure 8.1 is an example of a typical WPS written in accordance with the European Welding Standard format giving details of all the welding conditions that need to be specified.

8.1.1 Welding standards for procedure qualification

European and American Standards have been developed to give comprehensive details about:

- How a welded test piece must be made to demonstrate joint properties.
- How the test piece must be tested.
- What welding details need to be included in a WPS?
- The range of production welding allowed by a particular qualification test weld.

The principal **European Standards** that specify these requirements are:

BS EN ISO 15614 Specification and qualification of welding procedures for metallic materials – Welding procedure test.

Part 1: Arc & gas welding of steels & arc welding of nickel & nickel alloys.

Part 2: Arc welding of aluminium and its alloys.

The principal **American Standards** for procedure qualification are:

ASME Section IX for pressurised systems (vessels & pipework).

AWS D1.1 Structural welding of steels.

AWS D1.2 Structural welding of aluminium.

8.1.2 The qualification process for welding procedures

Although qualified WPS are usually based on test welds that have been made to demonstrate weld joint properties; welding standards also allow qualified WPS to be written based on other data (for some applications).

Some alternative ways that can be used for writing qualified WPS for some applications are:

- **Qualification by adoption of a standard welding procedure** - test welds previously qualified and documented by other manufacturers.
- **Qualification based on previous welding experience** - weld joints that have been repeatedly made and proved to have suitable properties by their service record.

Procedure qualification to European Standards by means of a test weld (and similar in ASME Section IX and AWS) requires a sequence of actions that is typified by those shown by Table 8.1.

A successful procedure qualification test is completed by the production of a welding procedure qualification record (WPQR), an example of which is shown by Figure 8.2.

8.1.3 Relationship between a WPQR and a WPS

Once a WPQR has been produced, the welding engineer is able to write **qualified WPSs** for the various production weld joints that need to be made.

The welding conditions that are allowed to be written on a qualified WPS are referred to as the **qualification range** and this range depends on the welding conditions that were used for the test piece (the as-run details) and form part of the WPQR.

Welding conditions are referred to as **welding variables** by European and American Welding Standards and are classified as either **essential variables** or **non-essential variables**.

These variables can be defined as follows:

- **Essential variable** a variable that has an effect on the mechanical properties of the weldment (and if changed beyond the limits specified by the standard will require the WPS to be re-qualified).
- **Non-essential variable** a variable that must be specified on a WPS but does not have a significant effect on the mechanical properties of the weldment (and can be changed **without need for re-qualification** but will require a new WPS to be written).

It is because essential variables can have a significant effect on mechanical properties that they are the controlling variables that govern the qualification range and determine what can be written into a WPS.

If a welder makes a production weld using conditions outside the qualification range given on a particular WPS, there is danger that the welded joint will not have the required properties and there are then two options:

- Make another test weld using similar welding conditions to those used for the affected weld and subject this to the same tests used for the relevant WPQR to demonstrate that the properties still satisfy specified requirements.
- Remove the affected weld and re-weld the joint strictly in accordance with the designated WPS.

Most of the welding variables that are classed as essential are the same in both the European and American Welding Standards but their qualification ranges may differ.

Some Application Standards specify their own essential variables and it is necessary to ensure that these are taken into consideration when procedures are qualified and WPSs are written.

Examples of essential variables (according to European Welding Standards) are given in Table 8.2.

8.2 Welder qualification

The use of qualified WPSs is the accepted method for controlling production welding but this will only be successful if the welders have the ability to understand and work in accordance with them.

Welders also need to have the skill to consistently produce sound welds (free from defects).

Welding Standards have been developed to give guidance on what particular test welds are required in order to show that welders have the required skills to make particular types of production welds in particular materials.

8.2.1 Welding standards for welder qualification

The principal **European Standards** that specify requirements are:

EN 287-1 / Qualification test of welders – Fusion welding
BS EN ISO 9606 Part 1: Steels

BS EN ISO 9606-2 Qualification test of welders – Fusion welding
Part 2: Aluminium and aluminium alloys

BS EN ISO 14732 Welding personnel. Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials

The principal **American Standards** that specify requirements for welder qualification are:

ASME Section IX Pressurised systems (vessels & pipework)

AWS D1.1 Structural welding of steels

AWS D1.2 Structural welding of aluminium

8.2.2 The qualification process for welders

Qualification testing of welders to European Standards requires test welds to be made and subjected to specified tests to demonstrate that the welder understands the WPS and can produce a sound weld.

For manual and semi-automatic welding the emphasis of the tests is to demonstrate ability to manipulate the electrode or welding torch.

For mechanised and automatic welding the emphasis is on demonstrating that welding operators have ability to control particular types of welding equipment.

American Standards allow welders to demonstrate that they can produce sound welds by subjecting their first production weld to non-destructive testing.

Table 8.3 shows the steps required for qualifying welders in accordance with European Standards.

Figure 8.5 shows a typical Welder Qualification Certificate in accordance with European Standards.

8.2.3 Welder qualification and production welding allowed

The welder is allowed to make production welds within the range of qualification recorded on his welder qualification certificate.

The range of qualification is based on the limits specified by the Welding Standard for **welder qualification essential variables** - defined as: *a variable that if changed beyond the limits specified by the Welding Standard may require greater skill than has been demonstrated by the test weld.*

Some welding variables that are classed as essential for welder qualification are the **same types** as those classified as essential for welding procedure qualification, but the range of qualification may be significantly wider.

Some essential variables are specific to welder qualification.

Examples of welder qualification essential variables are given in Table 8.4.

8.2.4 Period of validity for a welder qualification certificate

A welder's qualification begins from the date of welding of the test piece.

The European Standard allows a qualification certificate to remain valid for a period of two years – provided that:

- The welding co-ordinator, or other responsible person, can confirm that **the welder has been working within the initial range of qualification.**
- Working within the initial qualification range is confirmed every six months.

8.2.5 Prolongation of welder qualification

A welder's qualification certificate can be prolonged every two years by an examiner/examining body but before prolongation is allowed certain conditions need to be satisfied:

- Records/evidence are available that can be traced to the welder and the WPS that have been used for production welding.
- The supporting evidence must relate to volumetric examination of the welder's production welds (RT or UT) on two welds made during the 6 months prior to the prolongation date.
- The supporting evidence welds must satisfy the acceptance levels for imperfections specified by the European welding standard and have been made under the same conditions as the original test weld.

Table 8.1 Typical sequence for welding procedure qualification by means of a test weld.

The welding engineer writes a preliminary Welding Procedure Specification (pWPS) for each test coupon to be welded



- A welder makes the test coupon in accordance with the pWPS
- A welding inspector records all the welding conditions used to make the test coupon (called the as-run conditions)

*An Independent Examiner/ Examining Body/Third Party Inspector **may be** requested to monitor the procedure qualification*



The test coupon is subjected to NDT in accordance with the methods specified by the Standard – visual inspection, MT or PT and RT or UT



- The test coupon is destructively tested (tensile, bend, macro tests)
- The code/application standard/client may require additional tests such as hardness tests, impact tests or corrosion tests – depending on material and application



- A Welding Procedure Qualification Record (WPQR) is prepared by the welding engineer giving details of:
 - » **The as-run welding conditions**
 - » **Results of the NDT**
 - » **Results of the destructive tests**
 - » **The welding conditions allowed for production welding**
- If a Third Party Inspector is involved he will be requested to sign the WPQR as a true record of the test

Table 8.2 Typical examples of WPS essential variables according to European Welding Standards.

VARIABLE	RANGE for PROCEDURE QUALIFICATION
Welding process	No range – process qualified is process that must be used in production
PWHT	Joints tested after PWHT only qualify as PWHT production joints Joints tested 'as-welded' only qualify 'as-welded' production joints
Parent material type	Parent materials of similar composition and mechanical properties are allocated the same Material Group No.; qualification only allows production welding of materials with the same Group No.
Welding consumables	Consumables for production welding must have the same European designation – as a general rule
Material thickness	A thickness range is allowed – below and above the test coupon thickness
Type of current	AC only qualifies for AC; DC polarity (+VE or -VE) cannot be changed; pulsed current only qualifies for pulsed current production welding
Preheat temperature	The preheat temperature used for the test is the minimum that must be applied
Interpass temperature	The highest interpass temperature reached in the test is the maximum allowed
Heat input (HI)	When impact requirements apply maximum HI allowed is 25% above test HI when hardness requirements apply minimum HI allowed is 25% below test HI

Table 8.3 Stages for qualification of a welder.

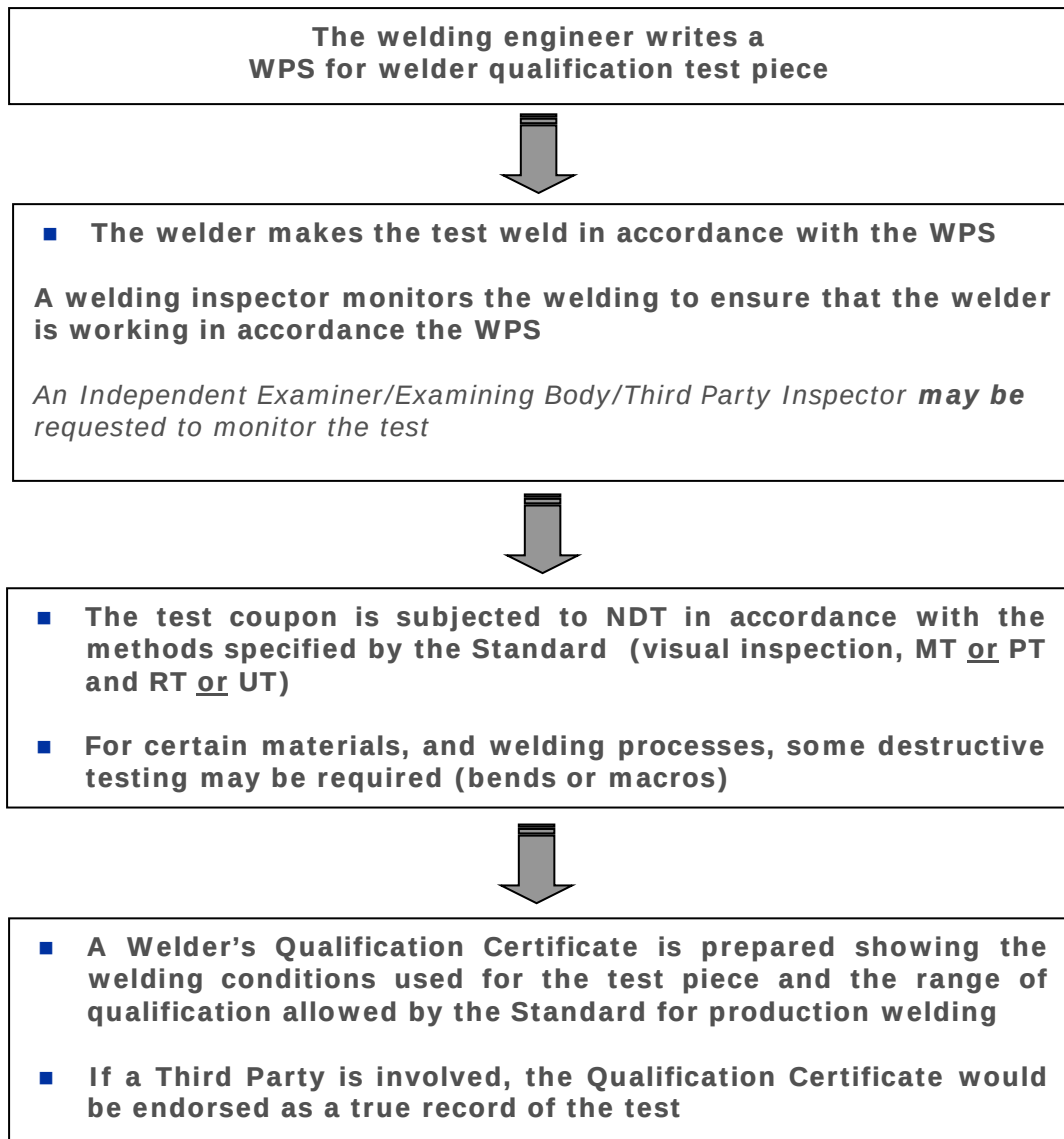


Table 8.4 Typical examples of welder qualification essential variables according to European Welding Standards.

VARIABLE	RANGE for WELDER QUALIFICATION
Welding process	No range – process qualified is process that a welder can use in production
Type of weld	Butt welds cover any type of joint except branch welds fillet welds only qualify fillets
Parent material type	Parent materials of similar composition and mechanical properties are allocated the same Material Group No.; qualification only allows production welding of materials with the same Group No. but the Groups allow much wider composition ranges than the procedure Groups
Filler material	Electrodes and filler wires for production welding must be of the same form as the test (solid wire, flux cored, etc); for MMA coating type is essential. The filler wire must fall within the range of the qualification of the filler material.
Material thickness	A thickness range is allowed; for test pieces above 12mm allow $\geq 5\text{mm}$
Pipe diameter	Essential and very restricted for small diameters; test pieces above 25mm allow $\geq 0.5 \times \text{diameter used (min. 25mm)}$
Welding positions	Position of welding very important; H-L045 allows all positions (except PG)

Weldspec

WPS record number	WPS - 031	Revision 0	Qualified to	EN 15614-1: 2004
Date	12/04/2006		Company name	TWI Ltd
Supporting PQR(s)	PQR-031 - Rev 0			
Reference docs.				

MATERIAL/JOINTS QUALIFIED		WELD/TEST CONDITIONS	
Joint type	Butt plate ss mb nb, bs gg ng : T-Butt ss bs : Fillet plate : Butt pipe ss mb nb : Fillet pipe	Without PWHT	
Parent metal(s)	Groups 8-8		
Notes			

TEST PIECE MATERIAL SPECIFICATION		MATERIAL SIZE QUALIFIED		Minimum	Maximum
Type	ASTM A213 TP316L	Grp-no.	8.1	Material thickness fillet (mm)	3.0 7.2
Welded to	ASTM A213 TP316L	Grp-no.	8.1	Material thickness butt (mm)	3.0 12.0
Backing	ASTM A213 TP316L	Grp-no.	8.1	Outside diameter (mm)	57.2 no max.
				Throat thickness (mm)	No Min No Max

WELDING PROCESSES	
Welding process	TIG
Type	Manual

FILLER METALS	
Filler metal manufacturer, trade name	METRODE 316S82
Filler metal designation type	Chemical
Filler metal designation	EN 12072 19 12 3 L
Filler metal size (mm)	2.4
Deposited thickness (mm)	3.0 - 12.0

POSITION	
Position of groove	All positions

PREHEAT	
Preheat temperature (°C)	4
Maximum interpass temperature (°C)	150

GAS	
Shielding gas type	EN 439 - I1
Flow rate (l/min)	10 to 12
Manufacturer, Trade name	n/a
Backing gas: Type	EN 439 - I1
Flow rate (l/min)	4
Manufacturer, Trade name	n/a

ELECTRICAL	
Filler metal size (mm)	2.4
Amperes	80 to 140
Volts	10 to 12
Travel speed (mm/min)	30 to 60
Maximum heat input (kJ/mm)	2.0
Tungsten size (mm)	2.4
Tungsten type	WT 20 (2% Thoria)
Current/polarity	DC -VE
DC pulsing current	None

TECHNIQUE	
String or weave	Stringer
Maximum width of run (mm)	n/a
Orifice/gas cup size	12
Multi/Single pass per side	Multi-pass only
Closed or out-of-chamber	Not applicable
Surface preparation	degreased before welding
Initial/interpass cleaning	Brushing
Back gouging method	None

Figure 8.1 Example of a welding procedure specification (WPS) to EN 15614 format.

Weldspec

PQR record number	WIS 5-002	Revision 0	pWPS record number	WIS 5 - p002	Revision 0
Date	27/03/2005				

Examiner/examining body	Third Party Ltd	Manufacturer	TWI Ltd
Reference number	TPL/TWI/WIS-002	Address	
Code/Testing standard	EN 15614-1: 2004		

EXTENT OF APPROVAL (JOINT/WELDING CONDITIONS)

Joint type	Butt plate ss mb nb, bs gg ng : T-Butt ss bs : Fillet plate : Fillet pipe
Parent metal(s)	Groups 1-1
Coupon thickness (mm)	17.5 - 70.0
Coupon outside diameter (mm)	Greater than 500.0
Fillet throat thickness (mm)	No Restriction
Branch angle (deg.)	n/a
Preheat (°C)	50
Interpass temperature (°C)	200
PWHT and/or ageing	-

EXTENT OF APPROVAL (PROCESS)

Welding process	111: MMA
Welding process type	Manual
Welded thickness (mm)	17.5 - 70.0
Welded outside diameter (mm)	Greater than 500.0
Filler metal type	en 499 e 46 6 mm fml b12 h5
Shielding gas/flux	none
Welding positions	PA,PC,PE,PF
Preheat temperature (°C)	50
Interpass temperature (°C)	200
Current/polarity	DC +VE
Multi/Single pass per side	Multi-pass only
Heat input (kJ/mm)	Max 3.2
Metal transfer mode	n/a
Backing gas	n/a

Figure 8.2 Example of a WPQR document (qualification range) to EN 15614 format.

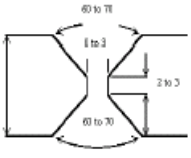
Weldspec

PQR record number	WIS 5-002	Revision 0	pWPS record number	WIS 5 - p002	Revision 0
Date	27/03/2006				

TEST PIECE MATERIAL SPECIFICATION

	Product form	Specification (type or grade)	Grp-no.	Size	Sch.	Thick. (mm)	Dia.(mm)
Welded to:	Plate	BS 10025	1.1	-	-	35	-
and tested:	Plate	BS 10025	1.1	-	-	35	-
Notes	Without PWHT, With Impacts						

TEST PIECE JOINT SPECIFICATION

Joint design	Butt-plate bs gg		
Backing:	gg: gouging or grinding		
Retainers			
Groove angle (deg.)	60		
Root opening (mm)	2.5		
Root face (mm)	2		

WELDING PROCESSES

Welding process	111: MMA
Type	Manual

FILLER METALS

Filler metal manufacturer, trade name	ESAB OK 53.08 Hytuf 1Ni
Filler metal designation type	Yield strength
Filler metal designation	EN 499 E 46 6 Mn1Ni B12 H5
Filler metal size (mm)	3.25 & 4.0
Deposited thickness (mm)	35
MMA Electrode coating	B basic

POSITION

Position of groove	PF
--------------------	----

PREHEAT

Preheat temperature (°C)	50
Maximum Interpass temperature (°C)	200

ELECTRICAL

Filler metal size (mm)	3.25 & 4.0
Amperes	3.25mm = 110; 4.0mm = 130
Volts	23 to 25
Electrode run out length (mm)	3.25mm=75min.; 4.0mm=125min.
Travel speed (mm/min)	60 to 70
Maximum heat input (kJ/mm)	2.6
Current/polarity	DC +ve

TECHNIQUE

String or weave	Stringer and Weave
Maximum width of run (mm)	8
Multi/Single pass per side	Multi-pass
Surface preparation	ground
Initial/Interpass cleaning	Brushing and Grinding
Back gouging method	arc-air

Figure 8.3 Example of WPQR document (test weld details) to EN 15614 format.

Weldspec

PQR record number	WIS 5-002	Revision 0	pWPS record number	WIS 5 - p002	Revision 0
Date	27/03/2006				

TENSILE TESTS

Type/Number	Re (N/mm ²)	Rm (N/mm ²)	A% on	Z%	Fracture location	Remarks
transverse	480	610	32	35	Ductile-Base Metal	
transverse	473	598	33	35	Ductile-Base Metal	

Comments 2 Transverse tensile tests according to EN 895

GUIDED BEND TESTS

Type/Number	Bend angle	Elongation*	Results
4 Side bend tests as per 7.4.3 and EN 910	EN 25817		Acceptable

Comments

TOUGHNESS TESTS

Notch location/direction	Temperature (°C)	Values (J)			Average (J)	Remarks
weld metal (surface)	-46	157	146	149	150.67	
weld metal (root)	-46	127	136	132	131.67	
FL (surface)	-46	67	78	63	69.33	
FL + 2 (surface)	-46	105	113	143	120.33	
FL + 5 (surface)	-46	216	203	215	211.33	

Comments

CERTIFICATION

Welder's name	ID Number	Stamp number	Mechanical testing by	The Test House
R.A.T. Catcher			Laboratory test number Test file number Tests conducted by	TTH - 1341-2006 1341-2006 I. A. M. Tougher

Certified that test welds were performed, welded and tested satisfactorily in accordance with the requirements of the code/testing standard indicated above.

Examiner or examining body

Name	Signature	Name	Signature
Date		Date	

Signature 3

Name	Signature	Name	Signature
Date		Date	

Signature 4

Weldspec 4.5.002

Catalog n° PQR00012

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Page 3 of 3

Figure 8.4 Example of a WPQR document (details of weld test) to EN 15614 format.

Welderqual

EN DESIGNATION

Designation	EN287-1, 111, T, BW, 1.1, B, t14.27, D168.28, H-L045, ss, nb
-------------	--

Welder's name	A. Weaver	Test date	06/07/2005
ID Number	AW-3463	WPQ record number	3463-001
Date of birth	12.3.79	Standard test number	n/a
Stamp number	3463	pWPS record number	WPS - 013
Company name	XYZ Fabrications	Qualification code	EN 287-1: 2004
Division	North East	Examining body	Third Party Ltd
Job knowledge	Not tested	Reference no.	TPL/XYZ/3463-1
		Expiry date	05/07/2007

BASE METALS

Product form	Specification (type or grade)	Grp-no.	Size	Sch.	Thick(mm)	Di(mm)
Welded to:	Pipe	BS 10025 (50-B)	1.1	152.40	120	14.27
	Pipe	BS 10025 (50-B)	1.1	152.40	120	14.27
Joint type	Butt					

VARIABLES	Actual values	RANGE QUALIFIED
Type of weld joint	Pipe - Butt	Butt, Fillet welds and Branch welds where angle >= 60°
Base metal	1.1 to 1.1	1.1, 1.2, 1.4

BASE METAL THICKNESS	Butt	Fillet	Butt	Fillet
Plate thickness (mm)	14.27	-	5.00 min	5.00 min
Pipe/tube thickness (mm)	14.27	-	5.00 min	5.00 min
Pipe diameter (mm)	168.28	-	84.14 and above	84.14 and above

VARIABLES	Actual values	RANGE QUALIFIED
Welding process	111: MMA	111: MMA
Type	Manual	Manual
Backing	nb: without backing	ss nb, ss mb, bs
Filler metal type/designation	EN 499 E 46 6 Mn Ni B	Any Similar
Filler metal group	n/a	Any Similar
Covered electrode type	B basic	B,A,RA,RS,RC,RR,R
Weld deposit thickness (mm)	12.70	5.00 min
Weld position (Actual position tested)	H-L045	
Butt-Plate		PA,PC,PF,PE
Fillet-Plate		PA,PB,PF,PD
Butt-Pipe		PA,PF,PC,H-L045
Fillet-Pipe		PA,PB,PF,PD
Butt-Pipe Diameter (see en287 6.3 a,c)		-

TESTS

Type of test	Acceptance criteria	Result	Comments
Visual examination per Table 10 and EN 970	EN ISO 5817	Acceptable	see - EN ISO 5817
Radiographic examination per Table 10 and EN 1435	EN ISO 5817	Acceptable	see - EN ISO 5817

Notes	branch set-on; angle at smallest required
-------	---

CERTIFICATION

Tests conducted by		Laboratory test number	
Mechanical tests by		Test file number	

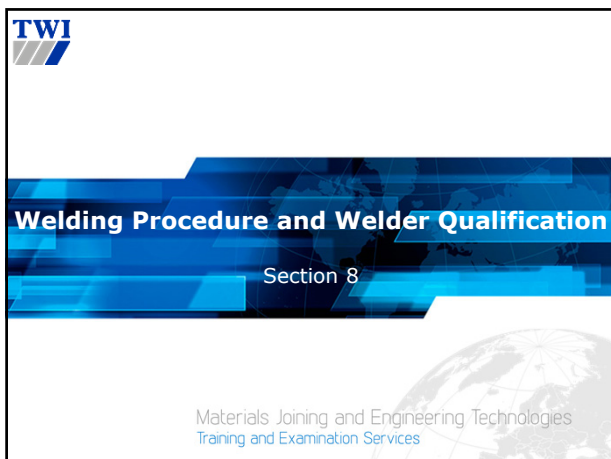
We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordance with the requirements of EN 287.

Signature 1 (defined using Tools-Options-Default Settings)

Signature 2 (also user defined)

Name	Signature	Name	Signature
Date		Date	

Figure 8.5 Example of a welder qualification test certificate (WPQ) to EN 287 format.



Welding Procedure Qualification

Question:
What is the main reason for carrying out a Welding Procedure Qualification Test?
(What is the test trying to show?)

Answer:
To show that the welded joint has the **properties*** that satisfy the design requirements (fit for purpose).

*** Properties**

- Mechanical properties are the main interest - **always strength** but toughness & hardness may be important for some applications.
- Test also demonstrates that the weld can be made without defects.

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Welding Procedures

Purpose of a WPS

- To achieve specific properties.
 - Mechanical strength, corrosion resistance, composition.
- To ensure freedom from defects.
- To enforce QC procedures.
- To standardise on methods and costs.
- To control production schedules.
- To form a record.
- Application standard or contract requirement.

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Welding Procedures

Object of a welding procedure test

- To give maximum confidence that the welds mechanical and metallurgical properties meet the requirements of the applicable code/specification.
- Each welding procedure will show a range to which the procedure is approved (extent of approval).
- If a customer queries the approval evidence can be supplied to prove its validity.

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Welding Procedure Qualification

(according to BS EN ISO 15614)

Preliminary Welding Procedure Specification (pWPS)

Welding Procedure Qualification Record (WPQR)

Welding Procedure Specification (WPS)

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Welding Procedures

Producing a welding procedure involves

- Planning the tasks.
- Collecting the data.
- Writing a procedure for use of for trial.
- Making a test welds.
- Evaluating the results.
- Approving the procedure.
- Preparing the documentation.

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Welding Procedure Qualification

Preliminary Welding Procedure Specification (pWPS)

Welding Engineer writes a **preliminary** Welding Procedure Specification (**pWPS**) for each test weld to be made.

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Welding Procedure Qualification

Welding Procedure Qualification Record (WPQR)

- A welder makes a test weld in accordance with the **pWPS**.
- A welding inspector records all the welding conditions used for the test weld (referred to as the 'as-run' conditions).

An Independent Examiner/ Examining Body/ Third Party inspector may be requested to monitor the qualification process.

The finished test weld is subjected to NDT in accordance with the methods specified by the EN ISO Standard - Visual, MT or PT & RT or UT.

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Welding Procedure Qualification

Welding Procedure Qualification Record (WPQR)

- Test weld is subjected to destructive testing (tensile, bend, macro).
- The Application Standard, or Client, may require additional tests such as impact tests, hardness tests (and for some materials - corrosion tests).

Welding Procedure Qualification Record (WPQR)

- The welding conditions used for the test weld
 - Results of the NDT.
 - Results of the destructive tests.
 - The welding conditions that the test weld allows for production welding.
- The **Third Party** may be requested to sign the WPQR as a true record.

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Welding Procedure Qualification

Welding Procedure Specification (WPS)

- The welding engineer writes **qualified** Welding Procedure Specifications (WPS) for production welding.
- Production **welding conditions** must remain within the **range of qualification** allowed by the **WPQR**.

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Welding Procedure Qualification

(according to EN Standards)

Welding conditions are called **welding variables**.

Welding variables are classified by the EN ISO Standard as:

- Essential variables.
- Non-essential variables.
- Additional variables.

Note: Additional variables = ASME supplementary essential.

The **range of qualification** for production welding is based on the limits that the EN ISO Standard specifies for **essential variables***

(* and when applicable - the additional variables)

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Welding Procedure Qualification

(according to EN Standards)

Welding essential variables

Question:
Why are some welding variables classified as **essential**?

Answer:
A variable, that if changed beyond certain limits (specified by the Welding Standard) may have a **significant effect** on the **properties*** of the joint.

* particularly joint strength and ductility.

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Welding Procedure Qualification

(according to EN Standards)

Welding additional variables

Question:
Why are some welding variables classified as **additional**?

Answer:
A variable, that if changed beyond certain limits (specified by the Welding Standard) may have a **significant effect** on the **toughness** and/or **hardness** of the joint.

Note: ASME calls variables that affect toughness as supplementary essential variables (but does not refer to hardness).

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Welding Procedure Qualification

(according to EN Standards)

Some typical essential variables

- Welding process.
- Post weld heat treatment (PWHT).
- Material type.
- Electrode type, filler wire type (Classification).
- Material thickness.
- Polarity (AC, DC+ve/DC-ve).
- Pre-heat temperature.

Some typical additional variables

- Heat input.
- Welding position.

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Welding Procedures

In most codes reference is made to how the procedure are to be devised and whether approval of these procedures is required.

The approach used for procedure approval depends on the code.

Example codes

- AWS D.1.1: Structural Steel Welding Code.
- BS 2633: Class 1 welding of Steel Pipe Work.
- API 1104: Welding of Pipelines.
- BS 4515: Welding of Pipelines over 7 Bar.

Other codes may not specifically deal with the requirement of a procedure but may contain information that may be used in writing a weld procedure.

- EN 1011: Process of Arc Welding Steels.

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Welding Procedures

Components of a welding procedure

Parent material

- Type (Grouping).
- Thickness.
- Diameter (Pipes).
- Surface condition.

Welding process

- Type of process (MMA, MAG, TIG, SAW etc).
- Equipment parameters.
- Amps, volts, travel speed.

Welding consumables

- Type of consumable/diameter of consumable.
- Brand/classification.
- Heat treatments/storage.

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Welding Procedures

Components of a welding procedure

Joint design

- Edge preparation.
- Root gap, root face.
- Jigging and tacking.
- Type of backing

Welding position

- Location, shop or site.
- Welding position e.g. PA, PB, PC etc.
- Any weather precaution.

Thermal heat treatments

- Preheat, temps.
- Post weld heat treatments eg stress relieving.

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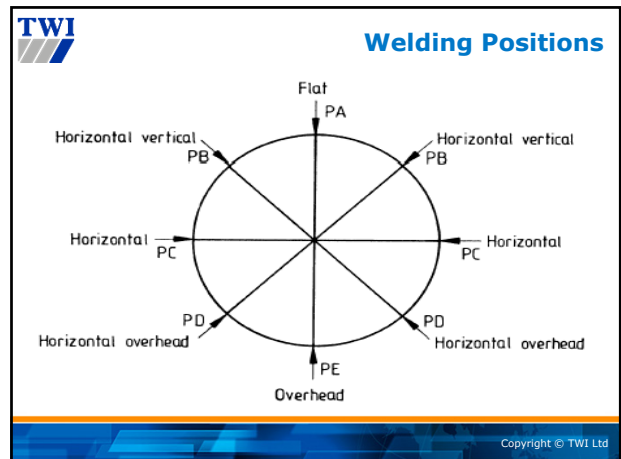
Welding Procedures

Example Welding Procedure Specification (WPS)

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TWI Welding Positions		
PA	1G / 1F	Flat / Downhand
PB	2F	Horizontal-Vertical
PC	2G	Horizontal
PD	4F	Horizontal-Vertical (Overhead)
PE	4G	Overhead
PF	3G / 5G	Vertical-Up
PG	3G / 5G	Vertical-Down
H-L045	6G	Inclined Pipe (Upwards)
J-L045	6G	Inclined Pipe (Downwards)

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Monitoring heat input

As Required by BS EN ISO 15614-1:2004
In accordance with BS EN 1011-1:1998

- When impact requirements apply, the upper limit of heat input qualified is 25% greater than that used in welding the test piece.
- When hardness requirements apply, the lower limit of heat input qualified is 25% lower than that used in welding the test piece.
- Heat input is calculated in accordance with BS EN1011-1.
- If welding procedure tests have been performed at both a high and low heat input level, then all intermediate heat inputs are also qualified.

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15614-1-2-3

Specifies contents of WPS

"Shall give details of how a welding operation is to be performed and contain all relevant information".

Definitions

- Processes to be designated in accordance with BS EN ISO 4063.
- Welding positions in accordance with BS EN ISO 6947.
- Typical WPS form.

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BS EN ISO 15614-1:2004 (Replaced BS EN 288-3)

"does not invalidate previous ... approvals made to former national standards... providing the intent of the technical requirements is satisfied... approvals are relevant"

"where additional tests... make the approval technically equivalent... only necessary to do the additional tests..."

"approval is valid... in workshops or sites under the same technical and quality control of that manufacturer..."

"service, material or manufacturing conditions may require more comprehensive testing..."

Application standard may require more testing

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Table 5 BS EN ISO 15614-1:2004

Thickness of test piece t	Range of qualification	
	Single run	Multi run
$t \leq 3$	0.7t to 1.3t ^a	0.7t to 2t
$3 < t \leq 12$	0.5t (3 min) to 1.3t ^a	3 to 2t ^a
$12 < t \leq 100$	0.5t to 1.1t	0.5t to 2t
$t > 100$	Not applicable	50 to 2t

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TWI Welding Procedures			
Table 6 BS EN ISO 15614-1:2004			
Thickness of test piece t	Material Thickness	Range of qualification	
		Throat Thickness	
		Single run	Multi run
$t \leq 3$	0.7 to 2 t	0.75 a to 1.5 a	No restriction
$3 < t < 30$	0.5t (3 min) to 1.2 t	0.75 a to 1.5 a	No restriction
$t \geq 30$	≥ 5	a	No restriction

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TWI Welding Procedures	
BS EN ISO 15614-1:2004 (Replaced BS EN 288-3)	
Covers Arc & Gas Welding of Steels & Arc Welding of Nickel & Nickel Alloys	
111 - MMA	114 - FCAW - no gas shield
12 - SAW	131 - MIG
135 - MAG	136 - FCAW - active gas
137 - FCAW - inert gas	141 - TIG
15 - PLASMA ARC	311 - Oxy-Acetylene
The principle of this European Standard may be applied to other fusion welding processes	

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TWI Welding Procedures	
Note 1: a is the throat as used for the test piece. Note 2: Where the fillet weld is qualified by means of a butt test, the throat thickness range qualified shall be based on the thickness of the deposited metal. For special applications only. Each fillet weld shall be proofed separately by a welding procedure test.	

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TWI Welding Procedures	
TABLE 7 BS EN ISO 15614-1:2004	
Diameter of the test piece D ^a , mm	Range of Qualification
$D \leq 25$	0.5 D to 2 D
$D > 25$	$\geq 0.5 D$ (25 mm min)
Note: For structural hollow sections D is the dimension of the smaller side	
^a D is the outside diameter of the pipe or outside diameter of the branch pipe	

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TWI CSWIP 3.2 Welding Inspection	
Welder Approval	

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TWI Welder Qualification	
(according to BS EN Standards)	
Question: What is the main reason for qualifying a welder? Answer: To show that he has the skill to be able to make production welds that are free from defects. Note: When welding in accordance with a Qualified WPS.	

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Welder Qualification

(according to BS EN ISO 9606)

An approved WPS should be available covering the range of qualification required for the welder approval.

- The welder qualifies in accordance with an approved WPS.
- A welding inspector monitors the welding to make sure that the welder uses the conditions specified by the WPS.

EN Welding Standard states that an Independent Examiner, Examining Body or Third Party Inspector **may be** required to monitor the qualification process.

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Welder Qualification

(according to BS EN ISO 9606)

The finished test weld is subjected to NDT by the methods specified by the EN Standard - Visual, MT or PT & RT or UT.

The test weld may need to be destructively tested - for certain materials and/or welding processes specified by the EN Standard or the Client Specification.

- A Welder's Qualification Certificate is prepared showing the conditions used for the test weld and the range of qualification allowed by the EN Standard for production welding.
- The Qualification Certificate is usually endorsed by a Third Party Inspector as a true record of the test.

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Welder Qualification

(according to BS EN ISO 9606)

The welder is allowed to make production welds within the range of qualification shown on the Certificate.

The range of qualification allowed for production welding is based on the limits that the EN Standard specifies for the welder qualification essential variables.

A Welder's Qualification Certificate automatically expires if the welder has not used the welding process for 6 months or longer.

A Certificate may be withdrawn by the Employer if there is reason to doubt the ability of the welder, for example

- A high repair rate.
- Not working in accordance with a qualified WPS.

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Welder Qualification

(according to BS EN ISO 9606)

Essential variables

Question:

What is a 'welder qualification essential variable'?
(what makes the variable 'essential'?)

Answer:

A variable, that if changed beyond the limits specified by the EN Standard, may require more skill than has been demonstrated by the test weld.

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Welder Qualification

(according to BS EN ISO 9606)

Typical Welder Essential Variables

- Welding process.
- Material type.
- Electrode type.
- Material thickness.
- Pipe diameter.
- Welding position.
- Weld backing (an unbacked weld requires more skill).

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Welder Qualification

Numerous codes and standards deal with welder qualification, eg BS EN ISO 9606

- Once the content of the procedure is approved the next stage is to approve the welders to the approved procedure.
- A welders test known as a Welders Qualification Test (WQT).

Object of a welding qualification test:

- To give maximum confidence that the welder meets the quality requirements of the approved procedure (WPS).
- The test weld should be carried out on the same material and same conditions as for the production welds.

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Welder Qualification

Information that should be included on a welders test certificate are:

- Welders name and identification number.
- Date of test and expiry date of certificate.
- Standard/code eg **BS EN ISO 9606**.
- Test piece details.
- Welding process.
- Welding parameters, amps, volts
- Consumables, flux type and filler classification details.
- Sketch of run sequence.
- Welding positions.
- Joint configuration details.
- Material type qualified, pipe diameter etc.
- Test results, remarks.
- Test location and witnessed by.
- Extent (range) of approval.

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Welder Qualification

The inspection of a welders qualification test

- It is normal for a qualified inspectors usually from an independent body to witness the welding.
- Under normal circumstances only one test weld per welder is permitted.
- If the welder fails the test weld and the failure is not the fault of the welder eg faulty welding equipment then a re-test would be permitted.
- **The testing of the test weld is done in accordance with the applicable code.**
- **It is not normal to carry out tests that test for the mechanical properties of welds eg tensile, charpy and hardness tests.**

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Welder Qualification



Example:
Welder
Approval
Qualification
Certification

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Welding Procedures and Welder Qualifications

You are in the process of ensuring that welding procedures and qualified welders are available for a new project involving many materials and processes.

You have to ensure that they all comply with the TWI specification.

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Question 1

Within the range of variables in a welding procedure, DC+ has been stated for the root pass.

- a. This would allow the use of DC- also
- b. This would allow the use of AC also
- c. In accordance with the Specification, any polarity could now be used
- d. In accordance with the specification only DC+ can be used

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Question 2

Using the TWI specification, which of the following is true for welder qualifications?

- a. Plate and pipe require separate qualifications
- b. Plate qualifies pipe
- c. Pipe qualifies plate
- d. It depends on whether it is fillet weld or butt weld

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Question 3

Which of the following NDT test is specified for all types of Stainless steel welds?

- a. Visual
- b. Radiographic
- c. Dye penetrant
- d. All options are correct

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Question 4

If a welding current of 145A was used on the test plate during qualification, on the actual job while using this procedure, the maximum current permitted is?

- a. 175A
- b. 125A
- c. 166A
- d. 200A

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Question 5

With respect to the validity of using a procedure in different positions, which one of the following is acceptable?

- a. Procedure is always valid only for the position tested
- b. Procedure is always valid for all the positions when impacts are specified
- c. Procedure qualified in vertical up position qualifies for that position only when impacts are specified
- d. Procedure is valid for all positions only for butt welds when impacts are specified

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Question 6

If a welder tests on a plate thickness of 14 mm, he is qualified to weld which of the following thicknesses?

- a. 14 mm
- b. 5-14 mm
- c. 5-28 mm
- d. 14 mm and above

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Question 7

For qualifying a welder for butt welding austenitic stainless steels, 14 mm thick plate, using the TIG process, which of the following tests are not required?

- a. Fillet fracture
- b. Macro examination
- c. Hardness tests
- d. All of the above

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Question 8

Which one of the following changes does not require re-qualification of a welder?

- a. Change from PF to PG
- b. Change from fillet to butt
- c. Change from pipe to plate
- d. Change from rutile to low hydrogen consumable

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Question 9

Which one of the following is true?

- a. Cellulosic qualifies rutile types also
- b. PG qualifies PG only
- c. The addition of a backing strip requires requalification
- d. Change from argon to carbon dioxide

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Question 10

If a welder fails a qualification test due to lack of skill, how many are allowed?

- a. One
- b. Two
- c. No retests are allowed
- d. No limit for retests

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Section 9

Arc Energy and Heat Input

9 Arc Energy and Heat Input

9.1 Current and voltage

The amount of electrons on the move defines the amount of electricity that flows termed **current**. **i** and measured in **amps, A**. Electron flow and therefore electricity, move at the speed of light as, rather than being the movement of small solid particles, it is a form of electromagnetic wave, but as this takes us into the realm of relativity we will not offer a proof of that here. Suffice to say that, for all practical purposes, electricity is instantaneously available throughout a circuit.

The differential of the positive and negative used to attract the electrons from one to the other can be regarded as the driving force. This is called the **potential difference** or **voltage**. Because of this potential there is a tendency for the electrons to move, ie there is a force attempting to move them from the negative to the positive. This force is called the **electromotive force, (emf)**, and is measured in **volts, V**.

9.2 Arc Energy or heat Input

Amperage and voltage are the two main parameters used when measuring the welding arc but so is the travel speed. These three variables are used to calculate the arc energy or heat input, measured in kilo Joules per mm of weld length. In general, this measurement is from 0.2 to 3.5 Kj per mm but there are occasions when it can drop below or go above this range.

This measurement is used as a point of reference and is quoted on documentation, such as a weld procedure. It can have a significant effect on a materials properties, distortion and residual stress, depending on how high or low the value is. Therefore, knowing the importance and how to calculate it is essential for anybody involved in the process.

Arc energy, is generally the term used in conjunction with heat input although in reality they are different measurements. Arc energy, is the energy generated at the welding arc using a simple formula. Heat input is the energy generated in the workpiece from the welding arc using a slightly different formula. Essentially they are the same thing but once one type of measurement has been selected, you should not deviate between the two or errors will occur.

American standards use the term heat input but the energy is measured at the arc whereas the end standards use the term heat input which is the actual energy transferred to the material. These measurements will be different in each case, EN generally has lower values as the EN standards take into account the thermal efficiency value of the welding process known as the "K" factor. Therefore, the standards dictating which type of measurement shall be recorded although a Senior Welding Inspector should have a knowledge of both.

Arc energy is reasonably easy to calculate, the amperage and voltage used are multiplied together and divided by the travel speed in mm per second multiplied by 1000 to give the Kj per mm.

Example

A MAG weld is made and the following conditions were recorded:

- Arc volts = 24.
- Welding amperage = 240.
- Travel speed = 300mm/minute.

What is the arc energy?

$$\begin{aligned}\text{Arc energy (kJ/mm)} &= \frac{\text{Volts} \times \text{amps}}{\text{Travel speed (mm/ sec)} \times 1000} \\ &= \frac{24 \times 240}{(300/60) \times 1000} \\ &= \frac{5760}{5000}\end{aligned}$$

Arc energy = 1.152 or 1.2kJ/mm

To calculate heat input, the amount of energy produced in the work piece, we can use the same values as before but multiply the amperage and voltage values by what's known as the efficiency value. This is based on the fact that a certain amount of energy is lost through the arc and depending on the welding process, more or less of this energy is lost. For example, SAW does not lose any energy mainly due to insulation of the granular flux whereas the TIG process loses 40% through conduction, convection and radiation.

Efficiency values via process:

- SAW = 1.0.
- MIG/MAG, FCAW and MMAW = 0.8.
- TIG and PLASMA = 0.6.

If we use the same worked example of the MAG process but this time calculate heat input it will be evident the value has dropped by 20%. Therefore, it is essential that the values recorded are either kept the same or labelled as heat input or arc energy.

Example

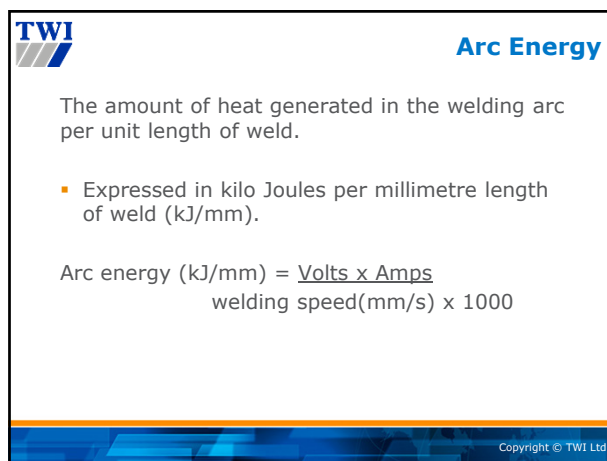
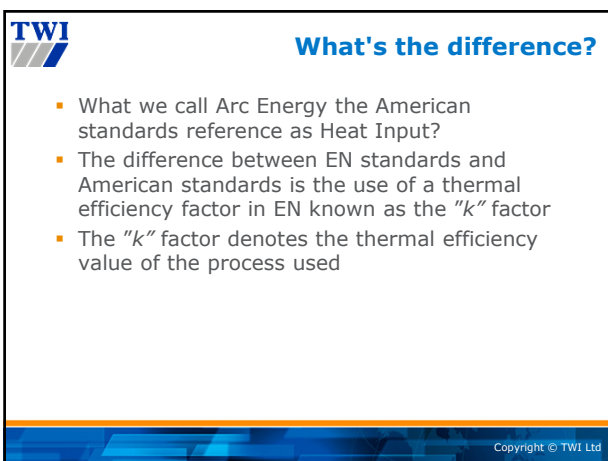
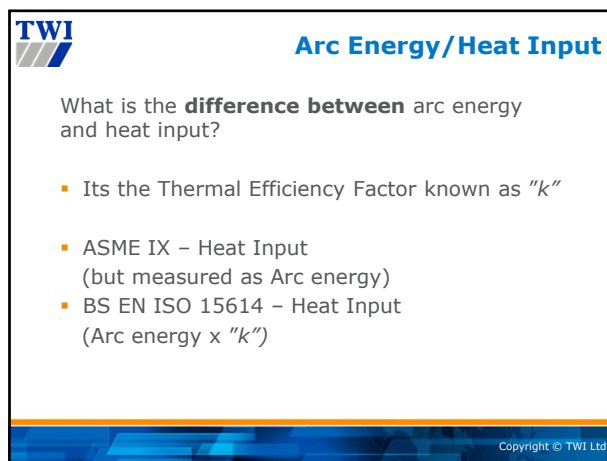
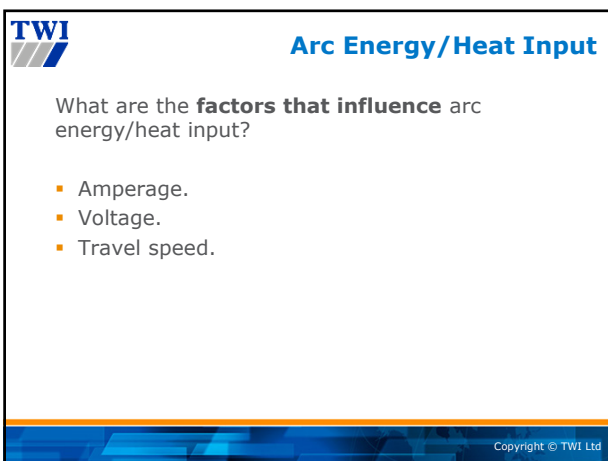
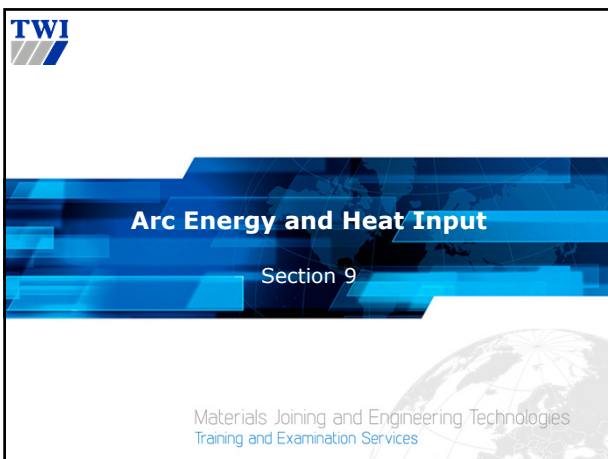
A MAG weld is made and the following conditions were recorded:

- Arc volts = 24.
- Welding amperage = 240.
- Travel speed = 300mm/minute.

What is the heat input?

$$\begin{aligned}\text{Heat input (kJ/mm)} &= \frac{\text{Volts} \times \text{amps} \times 0.8 \text{ (efficiency value)}}{\text{Travel speed (mm/sec)} \times 1000} \\ &= \frac{24 \times 240 \times 0.8}{(300/60) \times 1000} \\ &= \frac{4608}{5000}\end{aligned}$$

Heat input = 0.92kJ/mm





Heat Input

The energy supplied by the welding arc to the work piece.

Expressed in terms of
arc energy x thermal efficiency factor

Thermal efficiency factor is the ratio of heat energy introduced into the weld to the electrical energy consumed by the arc.

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Heat Input

Heat input values for various welding processes can be calculated from the arc energy by multiplying by the following

- Thermal efficiency factors;

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Arc Energy/Heat Input

Thermal efficiency factor k of welding processes

Process No	Process	Factor k
121	Submerged arc welding with wire	1.0
111	Metal-arc welding with covered electrodes	0.8
131	MIG welding	0.8
135	MAG welding	0.8
114	Flux-cored wire metal-arc welding without gas shield	0.8
136	Flux-cored wire metal-arc welding with active gas shield	0.8
137	Flux-cored wire metal-arc welding with inert gas shield	0.8
138	Metal-cored wire metal-arc welding with active gas shield	0.8
139	Metal-cored wire metal-arc welding with inert gas shield	0.8
141	TIG welding	0.6
15	Plasma arc welding	0.6

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Arc Energy Calculation

Example

A MAG weld is made and the following conditions were recorded:

- Arc volts = 24.
- Welding amperage = 240.
- Travel speed = 300mm/minute.

What is the arc energy and heat input?

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Arc Energy Calculation

$$AE \text{ (kJ/mm)} = \frac{\text{Volts} \times \text{amps}}{\text{TS (mm/sec)} \times 1000}$$

$$= \frac{24 \times 240}{(300/60) \times 1000}$$

$$= \frac{5760}{5000}$$

$$\text{Arc Energy} = 1.152 \text{ or } 1.2 \text{ kJ/mm}$$

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Heat Input

$$AE \text{ (kJ/mm)} = \frac{\text{Volts} \times \text{amps} \times 60 \times 0.8}{\text{TS (mm/min)} \times 1000}$$

$$= \frac{24 \times 240 \times 60 \times 0.8}{300 \times 1000}$$

$$= \frac{276480}{300000}$$

$$\text{Heat Input} = 0.92 \text{ kJ/mm}$$

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TWI **Arc Energy/Heat Input**

Run out length for one electrode using stringer bead (narrow)

Run out length for one electrode using weave (wider bead)

Electrode progression

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TWI **Heat Input and Arc Energy**

In the near future your shop floor is likely to get fabrication jobs involving many critical materials in which controlling heat input will be required to achieve the desired properties.

The customer has already provided you with the specification, the TWI specification, which talks about welding of many materials and specifies heat input control for some of them.

It is generally felt by you and your team that a proper understanding of this vital area is required before initiating any fabrication activity.

Some of the queries raised during the discussions you had with your team are as detailed below and trying to answer them will bring in more clarity and will help in following correct practices during welding.

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TWI **Question 1**

What is the arc energy using process 121 when the parameters are 24V-225A-250mm per minute ?

- a. 1.3 KJ/mm
- b. 1.04KJ/mm
- c. 0.57KJ/mm
- d. 3.2KJ/mm

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TWI **Question 2**

The heat input for the TIG welding process using parameters 20V-125A-50mm per minute will be?

- a. 2.42KJ/mm
- b. 1.02KJ/mm
- c. 1.80 KJ/mm
- d. 0.8KJ/mm

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TWI **Question 3**

Using the preheat tables in the TWI specification, when welding C-Mn steels having a carbon equivalent of 0.38 and section combined thickness of 25 mm using MMA process with hydrogen scale C and a preheat of 125C with 22V-150A, Which welding speed falls within the permitted range of HI?

- a. 68mm/min
- b. 72mm/min
- c. 74mm/min
- d. 80mm/min

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TWI **Question 4**

When welding C-Mn steels, having a carbon equivalent of 0.40 and combined section thickness of 102 mm, using a preheat of 50C with MMA process with parameters 24V-100 mm per min. From those listed which is the maximum current permitted?

- a. 276A
- b. 372A
- c. 555A
- d. 434A

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Question 5

Which of the following is true?

- a. For a lower heat input, higher preheats are required
- b. For the same material, the heat input increases with decreasing hydrogen levels
- c. As preheat increases, the heat input increases
- d. A higher heat input cannot eliminate preheat

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Question 6

Which of the following materials have specific restrictions on heat input?

- a. Q&T steels
- b. Duplex stainless steels
- c. Aluminium
- d. All of the above options are correct

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Question 7

Using TIG process for welding 4043 aluminium alloy having a thickness of 4.2 mm, which of the following parameters will be acceptable?

- a. 20V, 25mm/min, 18A
- b. 20V, 25mm/min, 13A
- c. 21V, 25mm/min, 30A
- d. 20V, 25mm/min, 9A

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Question 8

When welding A514 grade material having a thickness of 15 mm, using a preheat of 100C, with the MMA process, which of the following parameters can be acceptable?

- a. 24V-210A-200mm/min
- b. 20V-210A-200mm/min
- c. 24V-210A-150mm/min
- d. 25V-250A-200mm/min

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Question 9

When welding duplex stainless steels, having 23.5% Chromium, using the TIG process, for a plate thickness of 12 mm, the heat input will be dependent on?

- a. The carbon content
- b. The preheat used
- c. Combined plate thickness
- d. None of the above

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Question 10

When welding 75mm Q&T steels with a maximum preheat of 100C, the minimum heat input is restricted to

- a. 2.5KJ/mm
- b. 3.2KJ/mm
- c. 4.8KJ/mm
- d. 5.0KJ/mm

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Section 10

Residual Stress and Distortion

10 Residual Stress and Distortion

10.1 What causes distortion?

Because welding involves highly localised heating of joint edges to fuse the material, non-uniform stresses are set up in the component because of expansion and contraction of the heated material.

Initially, compressive stresses are created in the surrounding cold parent metal when the weld pool is formed due to the thermal expansion of the hot metal (heat affected zone (HAZ)) adjacent to the weld pool. However, tensile stresses occur on cooling when the contraction of the weld metal and immediate HAZ is resisted by the bulk of the cold parent metal.

The magnitude of thermal stresses induced into the material can be seen by the volume change in the weld area on solidification and subsequent cooling to room temperature. For example, when welding C-Mn steel, the molten weld metal volume will be reduced by approximately 3% on solidification and the volume of the solidified weld metal/HAZ will be reduced by a further 7% as its temperature falls from the melting point of steel to room temperature.

If the stresses generated from thermal expansion/contraction exceed the yield strength of the parent metal, localised plastic deformation of the metal occurs. Plastic deformation causes a permanent reduction in the component dimensions and distorts the structure.

10.2 What are the main types of distortion?

Distortion occurs in several ways:

- Longitudinal shrinkage.
- Transverse shrinkage.
- Angular distortion.
- Bowing and dishing.
- Buckling.

Contraction of the weld area on cooling results in both **transverse** and **longitudinal** shrinkage.

Non-uniform contraction (through thickness) produces **angular** distortion as well as longitudinal and transverse shrinking.

For example, in a single V butt weld, the first weld run produces longitudinal and transverse shrinkage and rotation. The second run causes the plates to rotate using the first weld deposit as a fulcrum. Therefore balanced welding in a double side V butt joint can be used to produce uniform contraction and prevent angular distortion.

Similarly, in a single-sided fillet weld, non-uniform contraction will produce angular distortion of the upstanding leg. Double-sided fillet welds can therefore be used to control distortion in the upstanding fillet but because the weld is only deposited on one side of the base plate, angular distortion will now be produced in the plate.

Longitudinal **bowing** in welded plates happens when the weld centre is not coincident with the neutral axis of the section so that longitudinal shrinkage in the welds bends the section into a curved shape. Clad plate tends to bow in two directions due to longitudinal and transverse shrinkage of the cladding. This produces a dished shape.

Dishing is also produced in stiffened plating. Plates usually dish inwards between the stiffeners, because of angular distortion at the stiffener attachment welds.

In plating, long range compressive stresses can cause elastic buckling in thin plates, resulting in dishing, bowing or rippling, see below.

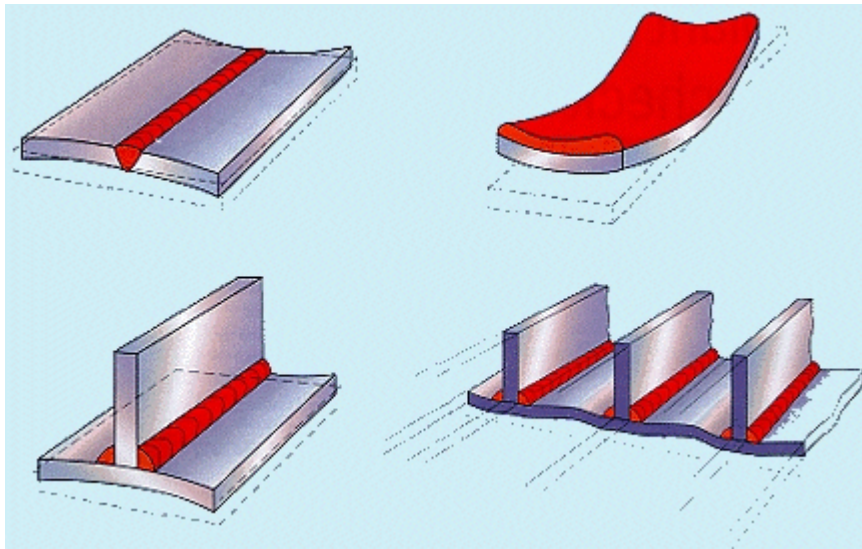


Figure 10.1 Examples of distortion.

Increasing the leg length of fillet welds, in particular, increases shrinkage.

10.3 What are the factors affecting distortion?

If a metal is uniformly heated and cooled there would be almost no distortion. However, because the material is locally heated and restrained by the surrounding cold metal, stresses are generated higher than the material yield stress causing permanent distortion. The principal factors affecting the type and degree of distortion are:

- Parent material properties.
- Amount of restraint.
- Joint design.
- Part fit-up.
- Welding procedure.

10.3.1 Parent material properties

Parent material properties, which influence distortion, are coefficient of thermal expansion, thermal conductivity, and to a lesser extent, yield stress and Young's modulus. As distortion is determined by expansion and contraction of the material, the coefficient of thermal expansion of the material plays a significant role in determining the stresses generated during welding and, hence, the degree of distortion. For example, as stainless steel has a higher coefficient of expansion and lesser thermal conductivity than plain carbon steel, it generally has significantly more distortion.

10.3.2 Restraint

If a component is welded without any external restraint, it distorts to relieve the welding stresses. So, methods of restraint, such as strongbacks in butt welds, can prevent movement and reduce distortion. As restraint produces higher levels of residual stress in the material, there is a greater risk of cracking in weld metal and HAZ especially in crack-sensitive materials.

10.3.3 Joint design

Both butt and fillet joints are prone to distortion, but it can be minimised in butt joints by adopting a joint type, which balances the thermal stresses through the plate thickness. For example, double- in preference to a single-sided weld. Double-sided fillet welds should eliminate angular distortion of the upstanding member, especially if the two welds are deposited at the same time.

10.3.4 Part fit-up

Fit-up should be uniform to produce predictable and consistent shrinkage. Excessive joint gap can also increase the degree of distortion by increasing the amount of weld metal needed to fill the joint. The joints should be adequately tacked to prevent relative movement between the parts during welding.

10.3.5 Welding procedure

This influences the degree of distortion mainly through its effect on the heat input. As welding procedures are usually selected for reasons of quality and productivity, the welder has limited scope for reducing distortion. As a general rule, weld volume should be kept to a minimum. Also, the welding sequence and technique should aim to balance the thermally induced stresses around the neutral axis of the component.

10.4 Distortion - prevention by pre-setting, pre-bending or use of restraint

Distortion can often be prevented at the design stage, for example, by placing the welds about the neutral axis, reducing the amount of welding and depositing the weld metal using a balanced welding technique. In designs where this is not possible, distortion may be prevented by one of the following methods:

- Pre-setting of parts.
- Pre-bending of parts.
- Use of restraint.

The technique chosen will be influenced by the size and complexity of the component or assembly, the cost of any restraining equipment and the need to limit residual stresses.

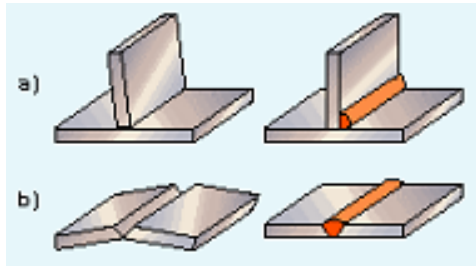


Figure 10.2 Pre-setting of parts to produce correct alignment after welding:

- a Pre-setting of fillet joint to prevent angular distortion;**
- b Pre-setting of butt joint to prevent angular distortion.**

10.4.1 Pre-setting of parts

The parts are pre-set and left free to move during welding (see above). In practice, the parts are pre-set by a pre-determined amount so that distortion occurring during welding is used to achieve overall alignment and dimensional control.

The main advantages compared with the use of restraint are that there is no expensive equipment needed and there will be lower residual stress in the structure.

Unfortunately, as it is difficult to predict the amount of pre-setting needed to accommodate shrinkage, a number of trial welds will be required. For example, when MMA or MIG/MAG welding butt joints, the joint gap will normally close ahead of welding; when submerged arc welding; the joint may open up during welding. When carrying out trial welds, it is also essential that the test structure is reasonably representative of the full size structure in order to generate the level of distortion likely to occur in practice. For these reasons, pre-setting is a technique more suitable for simple components or assemblies.

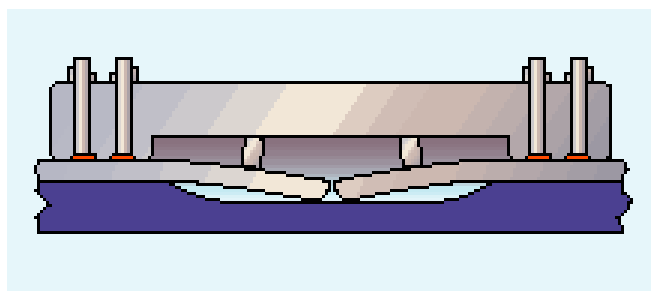


Figure 10.3 Pre-bending, using strongbacks and wedges, to accommodate angular distortion in thin plates.

10.4.2 Pre-bending of parts

Pre-bending, or pre-springing the parts before welding is used to pre-stress the assembly to counteract shrinkage during welding. As shown above, pre-bending by means of strongbacks and wedges can be used to pre-set a seam before welding to compensate for angular distortion. Releasing the wedges after welding will allow the parts to move back into alignment.

The figure shows the diagonal bracings and centre jack used to pre-bend the fixture, not the component. This counteracts the distortion introduced through out-of-balance welding.

10.4.3 Use of restraint

Because of the difficulty in applying pre-setting and pre-bending, restraint is the more widely practised technique. The basic principle is that the parts are placed in position and held under restraint to minimise any movement during welding. When removing the component from the restraining equipment, a relatively small amount of movement will occur due to locked-in stresses. This can be cured by either applying a small amount of pre-set or stress-relieving before removing the restraint.

When welding assemblies, all the component parts should be held in the correct position until completion of welding and a suitably balanced fabrication sequence used to minimise distortion.

Welding with restraint will generate additional residual stresses in the weld, which may cause cracking. When welding susceptible materials, a suitable welding sequence and the use of preheating will reduce this risk.

Restraint is relatively simple to apply using clamps, jigs and fixtures to hold the parts during welding.

Welding jigs and fixtures

Jigs and fixtures are used to locate the parts and ensure that dimensional accuracy is maintained whilst welding. They can be of a relatively simple construction, as shown in a) below but the welding engineer will need to ensure that the finished fabrication can be removed easily after welding.

Flexible clamps

A flexible clamp (b) below) can be effective in applying restraint and also setting-up and maintaining the joint gap (it can also be used to close a gap that is too wide).

A disadvantage is that as the restraining forces in the clamp will be transferred into the joint when the clamps are removed, the level of residual stress across the joint can be quite high.

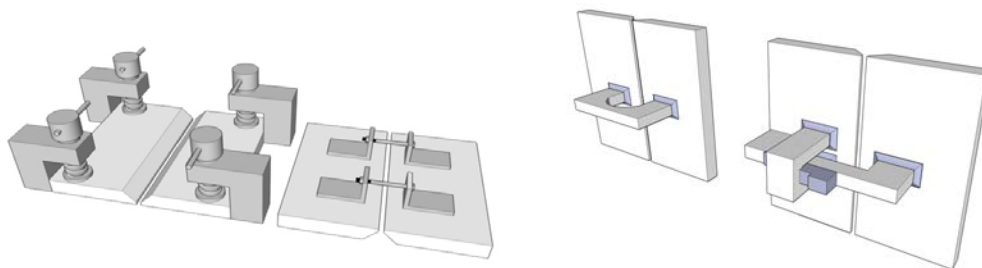


Figure 10.4 Restraint techniques to prevent distortion.

Strongbacks (and wedges)

Strongbacks are a popular means of applying restraint especially for site work. Wedged strongbacks (c)) above), will prevent angular distortion in plate and help prevent peaking in welding cylindrical shells. As these types of strongback will allow transverse shrinkage, the risk of cracking will be greatly reduced compared with fully welded strongbacks.

Fully welded strongbacks (welded on both sides of the joint) (d) above) will minimise both angular distortion and transverse shrinkage. As significant stresses can be generated across the weld, which will increase any tendency for cracking, care should be taken in the use of this type of strongback.

10.4.4 Best practice

Adopting the following assembly techniques will help to control distortion:

- Pre-set parts so that welding distortion will achieve overall alignment and dimensional control with the minimum of residual stress.
- Pre-bend joint edges to counteract distortion and achieve alignment and dimensional control with minimum residual stress.
- Apply restraint during welding by using jigs and fixtures, flexible clamps, strongbacks and tack welding but consider the risk of cracking which can be quite significant, especially for fully welded strongbacks.
- Use an approved procedure for welding and removal of welds for restraint techniques, which may need preheat to avoid forming imperfections in the component surface.

10.5 Distortion - prevention by design

Design principles

At the design stage, welding distortion can often be prevented, or at least restricted, by considering:

- Elimination of welding.
- Weld placement.
- Reducing the volume of weld metal.
- Reducing the number of runs.
- Use of balanced welding.

10.6 Elimination of welding

As distortion and shrinkage are an inevitable result of welding, good design requires that not only the amount of welding is kept to a minimum, but also the smallest amount of weld metal is deposited. Welding can often be eliminated at the design stage by forming the plate or using a standard rolled section, as shown below.

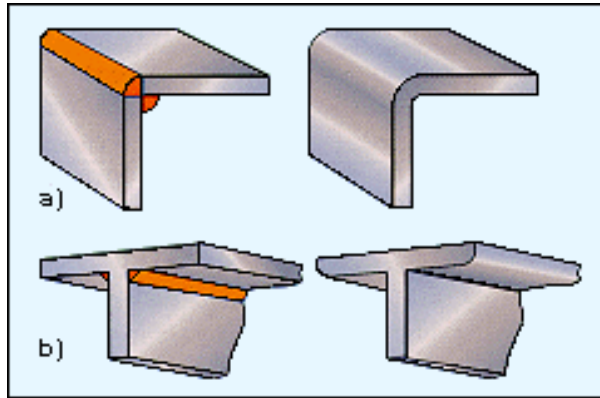


Figure 10.5 Elimination of welds by:

- a Forming the plate;**
- b Use of rolled or extruded section.**

If possible, the design should use intermittent welds rather than a continuous run, to reduce the amount of welding. For example, in attaching stiffening plates, a substantial reduction in the amount of welding can often be achieved whilst maintaining adequate strength.

10.6.1 Weld placement

Placing and balancing of welds are important in designing for minimum distortion. The closer a weld is positioned to the neutral axis of a fabrication, the lower the leverage effect of the shrinkage forces and the final distortion. Examples of poor and good designs are shown below.

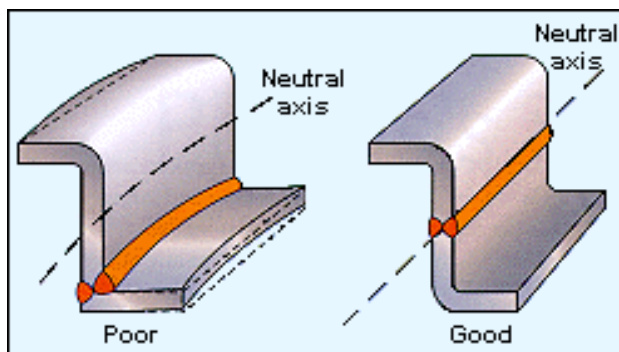


Figure 10.6 Distortion may be reduced by placing the welds around the neutral axis.

As most welds are deposited away from the neutral axis, distortion can be minimised by designing the fabrication so the shrinkage forces of an individual weld are balanced by placing another weld on the opposite side of the neutral axis. When possible, welding should be carried out alternately on opposite sides, instead of completing one side first. In large structures, if distortion is occurring preferentially on one side, it may be possible to take corrective actions, for example, by increasing welding on the other side to control the overall distortion.

10.6.2 Reducing the volume of weld metal

To minimise distortion, as well as for economic reasons, the volume of weld metal should be limited to the design requirements. For a single-sided joint, the cross-section of the weld should be kept as small as possible to reduce the level of angular distortion, as illustrated below.

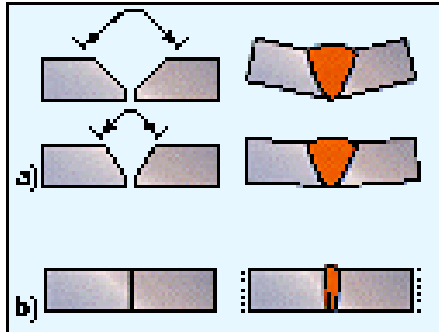


Figure 10.7 Reducing the amount of angular distortion and lateral shrinkage.

Ways of reducing angular distortion and lateral shrinkage:

- Reducing the volume of weld metal.
- Using single pass weld.
- Ensure fillet welds are not oversize.

Joint preparation angle and root gap should be minimised providing the weld can be made satisfactorily. To facilitate access, it may be possible to specify a larger root gap and smaller preparation angle. By cutting down the difference in the amount of weld metal at the root and face of the weld, the degree of angular distortion will be correspondingly reduced. Butt joints made in a single pass using deep penetration have little angular distortion, especially if a closed butt joint can be welded (see above). For example, thin section material can be welded using plasma and laser welding processes and thick section can be welded, in the vertical position, using electrogas and electroslog processes. Although angular distortion can be eliminated, there will still be longitudinal and transverse shrinkage.

In thick section material, as the cross-sectional area of a double V joint preparation is often only half that of a single V preparation, the volume of weld metal to be deposited can be substantially reduced. The double V joint preparation also permits balanced welding about the middle of the joint to eliminate angular distortion.

As weld shrinkage is proportional to the amount of weld metal both poor joint fit-up and over-welding will increase the amount of distortion. Angular distortion in fillet welds is particularly affected by over-welding. As design strength is based on throat thickness, over-welding to produce a convex weld bead does not increase the allowable design strength but will increase the shrinkage and distortion.

10.6.3 Reducing the number of runs

There are conflicting opinions on whether it is better to deposit a given volume of weld metal using a small number of large weld passes or a large number of small passes. Experience shows that for a single-sided butt joint, or fillet weld, a large single weld deposit gives less angular distortion than if the weld is made with a number of small runs. Generally, in an unrestrained joint, the degree of angular distortion is approximately proportional to the number of passes.

Completing the joint with a small number of large weld deposits results in more longitudinal and transverse shrinkage than a weld completed in a larger number of small passes. In a multi-pass weld, previously deposited weld metal provides restraint, so the angular distortion per pass decreases as the weld is built up. Large deposits also increase the risk of elastic buckling particularly in thin section plate.

10.6.4 Use of balanced welding

Balanced welding is an effective means of controlling angular distortion in a multi-pass butt weld by arranging the welding sequence to ensure that angular distortion is continually being corrected and not allowed to accumulate during welding. Comparative amounts of angular distortion from balanced welding and welding one side of the joint first are shown below. The balanced welding technique can also be applied to fillet joints.

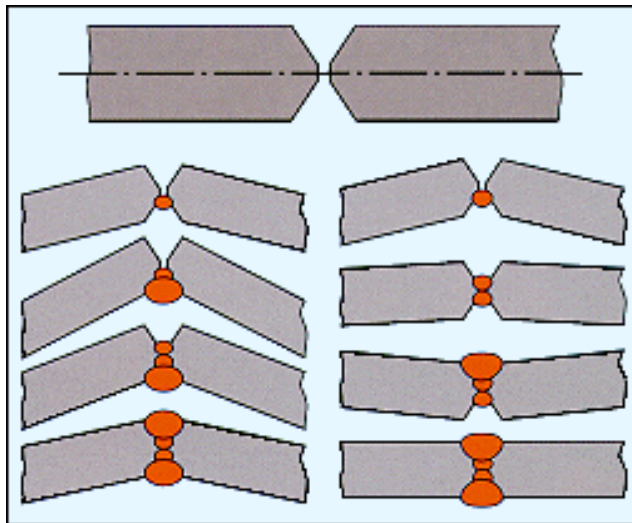


Figure 10.8 Balanced welding to reduce the amount of angular distortion.

If welding alternately on either side of the joint is not possible, or if one side has to be completed first, an asymmetrical joint preparation may be used with more weld metal being deposited on the second side. The greater contraction resulting from depositing the weld metal on the second side will help counteract the distortion on the first side.

10.6.5 Best practice

The following design principles can control distortion:

- Eliminate welding by forming the plate and using rolled or extruded sections.
- Minimise the amount of weld metal.
- Do not over-weld.
- Use intermittent welding in preference to a continuous weld pass.
- Place welds about the neutral axis.
- Balance the welding about the middle of the joint by using a double V joint in preference to a single.

Adopting best practice principles can have surprising cost benefits. For example, for a design fillet leg length of 6mm, depositing an 8mm leg length will result in the deposition of 57% additional weld metal. Besides the extra cost of depositing weld metal and the increase risk of distortion, it is costly to remove this extra weld metal later. However, designing for distortion control may incur additional fabrication costs. For example, the use of a double V joint preparation is an excellent way to reduce weld volume and control distortion, but extra costs may be incurred in production through manipulation of the workpiece for the welder to access the reverse side.

10.7 Distortion - prevention by fabrication techniques

10.7.1 Assembly techniques

In general, the welder has little influence on the choice of welding procedure but assembly techniques can often be crucial in minimising distortion. The principal assembly techniques are:

- Tack welding.
- Back-to-back assembly.
- Stiffening.

Tack welding

Tack welds are ideal for setting and maintaining the joint gap but can also be used to resist transverse shrinkage. To be effective, thought should be given to the number of tack welds, their length and the distance between them. With too few, there is the risk of the joint progressively closing up as welding proceeds. In a long seam, using MMA or MIG/MAG, the joint edges may even overlap. It should be noted that when using the submerged arc process, the joint might open up if not adequately tacked.

The tack welding sequence is important to maintain a uniform root gap along the length of the joint. Three alternative tack-welding sequences are shown below:

- Tack weld straight through to the end of the joint a). It is necessary to clamp the plates or to use wedges to maintain the joint gap during tacking.
- Tack weld one end and then use a back stepping technique for tacking the rest of the joint b).
- Tack weld the centre and complete the tack welding by back stepping c).

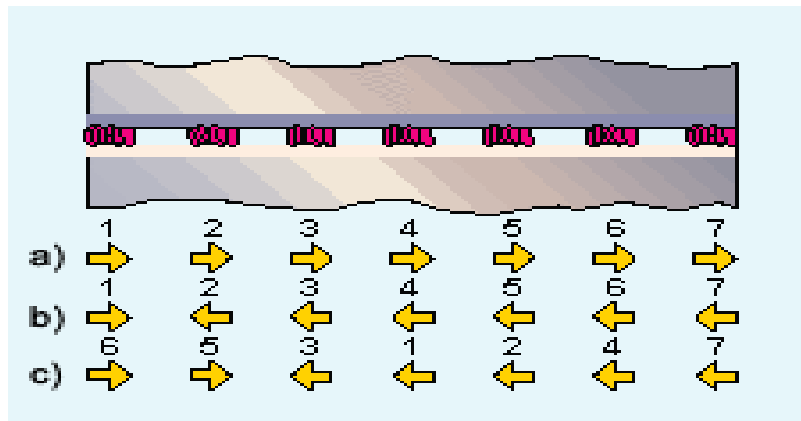


Figure 10.9 Alternative procedures used for tack welding to prevent transverse shrinkage.

Directional tacking is a useful technique for controlling the joint gap, for example closing a joint gap which is (or has become) too wide.

When tack welding, it is important that tacks which are to be fused into the main weld, are produced to an approved procedure using appropriately qualified welders. The procedure may require preheat and an approved consumable as specified for the main weld. Removal of the tacks also needs careful control to avoid causing defects in the component surface.

Back-to-back assembly

By tack welding or clamping two identical components back-to-back, welding of both components can be balanced around the neutral axis of the combined assembly (see a) on next page). It is recommended that the assembly is stress-relieved before separating the components. If stress-relieving is not done, it may be necessary to insert wedges between the components (b) on next page) so when the wedges are removed, the parts will move back to the correct shape or alignment.

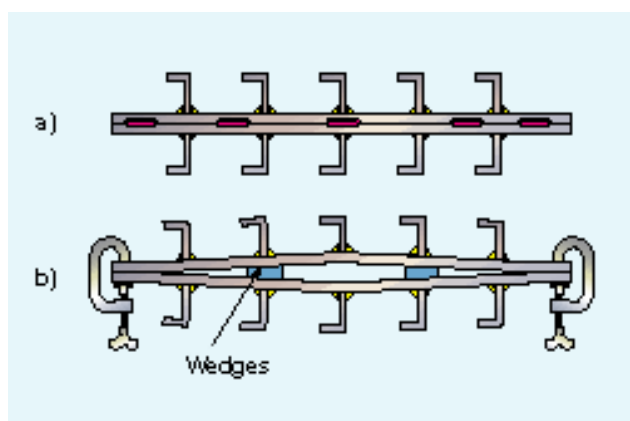


Figure 10.10 Back-to-back assembly to control distortion when welding two identical components:

- a Assemblies tacked together before welding;**
- b Use of wedges for components that distort on separation after welding.**

Stiffening

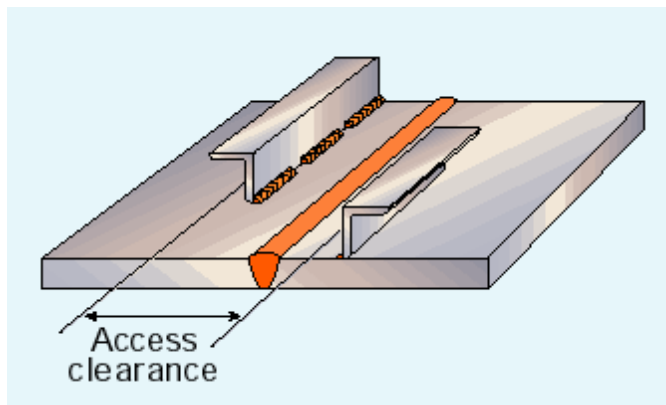


Figure 10.11 Longitudinal stiffeners prevent bowing in butt welded thin plate joints.

Longitudinal shrinkage in butt welded seams often results in bowing, especially when fabricating thin plate structures. Longitudinal stiffeners in the form of flats or angles, welded along each side of the seam (see above) are effective in preventing longitudinal bowing. Stiffener location is important: they must be at a sufficient distance from the joint so they do not interfere with welding, unless located on the reverse side of a joint welded from one side.

10.7.2 Welding procedure

A suitable welding procedure is usually determined by productivity and quality requirements rather than the need to control distortion. Nevertheless, the welding process, technique and sequence do influence the distortion level.

Welding process

General rules for selecting a welding process to prevent angular distortion are:

- Deposit the weld metal as quickly as possible.
- Use the least number of runs to fill the joint.

Unfortunately, selecting a suitable welding process based on these rules may increase longitudinal shrinkage resulting in bowing and buckling.

In manual welding, MIG/MAG, a high deposition rate process, is preferred to MMA. Weld metal should be deposited using the largest diameter electrode (MMA), or the highest current level (MIG/MAG), without causing lack-of-fusion imperfections. As heating is much slower and more diffuse, gas welding normally produces more angular distortion than the arc processes.

Mechanised techniques combining high deposition rates and welding speeds have the greatest potential for preventing distortion. As the distortion is more consistent, simple techniques such as pre-setting are more effective in controlling angular distortion.

Welding technique

General rules for preventing distortion are:

- Keep the weld (fillet) to the minimum specified size.
- Use balanced welding about the neutral axis.
- Keep the time between runs to a minimum.

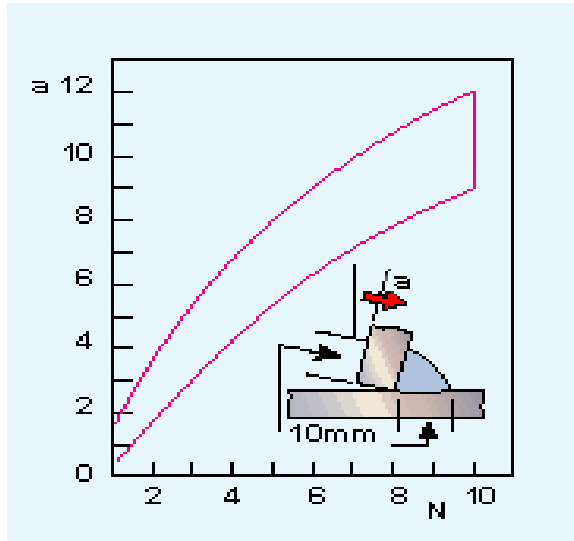


Figure 10.12 Angular distortion of the joint as determined by the number of runs in the fillet weld.

In the absence of restraint, angular distortion in both fillet and butt joints will be a function of the joint geometry, weld size and the number of runs for a given cross-section. Angular distortion (measured in degrees) as a function of the number of runs for a 10mm leg length fillet weld is shown above.

If possible, balanced welding around the neutral axis should be done, for example on double-sided fillet joints, by two people welding simultaneously. In butt joints, the run order may be crucial in that balanced welding can be used to correct angular distortion as it develops.

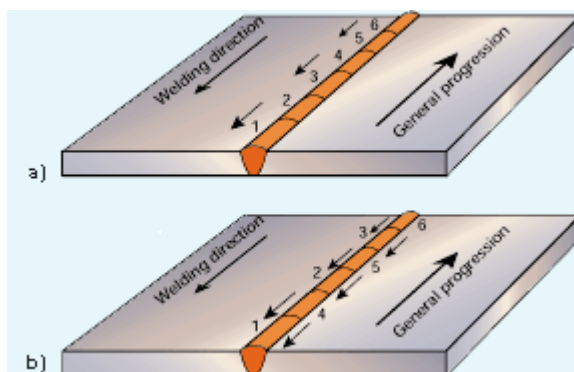


Figure 10.13 Use of welding direction to control distortion:

- a Back-step welding;**
- b Skip welding.**

Welding sequence

The welding sequence, or direction, of welding is important and should be towards the free end of the joint. For long welds, the whole of the weld is not completed in one direction. Short runs, for example using the back-step or skip welding technique, are very effective in distortion control (see above).

- Back-step welding involves depositing short adjacent weld lengths in the opposite direction to the general progression (see above).
- Skip welding is laying short weld lengths in a pre-determined, evenly spaced, sequence along the seam (b) in above figure). Weld lengths and the spaces between them are generally equal to the natural run-out length of one electrode. The direction of deposit for each electrode is the same, but it is not necessary for the welding direction to be opposite to the direction of general progression.

10.7.3 Best practice

The following fabrication techniques are used to control distortion:

- Using tack welds to set-up and maintain the joint gap.
- Identical components welded back-to-back so welding can be balanced about the neutral axis.
- Attachment of longitudinal stiffeners to prevent longitudinal bowing in butt welds of thin plate structures.
- Where there is choice of welding procedure, process and technique should aim to deposit the weld metal as quickly as possible; MIG/MAG in preference to MMA or gas welding and mechanised rather than manual welding.
- In long runs, the whole weld should not be completed in one direction; back-step or skip welding techniques should be used.

10.8 Distortion - corrective techniques

Every effort should be made to avoid distortion at the design stage and by using suitable fabrication procedures. As it is not always possible to avoid distortion during fabrication, several well-established corrective techniques can be employed. Reworking to correct distortion should not be undertaken lightly as it is costly and needs considerable skill to avoid damaging the component.

General guidelines are provided on best practice for correcting distortion using mechanical or thermal techniques.

10.8.1 Mechanical techniques

The principal mechanical techniques are hammering and pressing. Hammering may cause surface damage and work hardening.

In cases of bowing or angular distortion, the complete component can often be straightened on a press without the disadvantages of hammering. Packing pieces are inserted between the component and the platens of the press. It is important to impose sufficient deformation to give over-correction so that the normal elastic spring-back will allow the component to assume its correct shape.

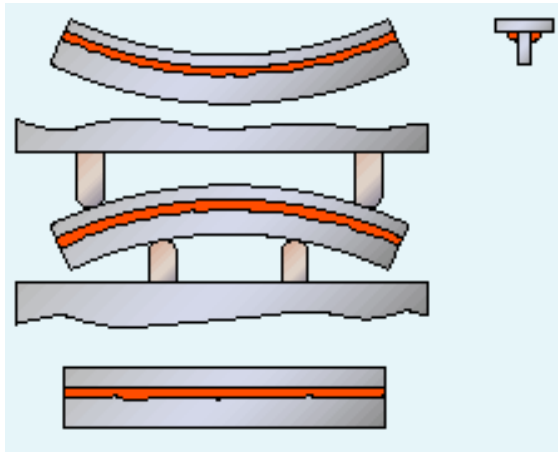


Figure 10.14 Use of press to correct bowing in T butt joint.

Pressing to correct bowing in a flanged plate is shown above. In long components, distortion is removed progressively in a series of incremental pressings; each one acting over a short length. In the case of the flanged plate, the load should act on the flange to prevent local damage to the web at the load points. As incremental point loading will only produce an approximately straight component, it is better to use a former to achieve a straight component or to produce a smooth curvature.

Best practice for mechanical straightening

The following should be adopted when using pressing techniques to remove distortion:

- Use packing pieces which will over correct the distortion so that spring-back will return the component to the correct shape.
- Check that the component is adequately supported during pressing to prevent buckling.
- Use a former (or rolling) to achieve a straight component or produce a curvature.
- As unsecured packing pieces may fly out from the press, the following safe practice must be adopted:
 - ☐ Bolt the packing pieces to the platen.
 - ☐ Place a metal plate of adequate thickness to intercept the missile.
 - ☐ Clear personnel from the hazard area.

10.8.2 Thermal techniques

The basic principle behind thermal techniques is to create sufficiently high local stresses so that, on cooling, the component is pulled back into shape.

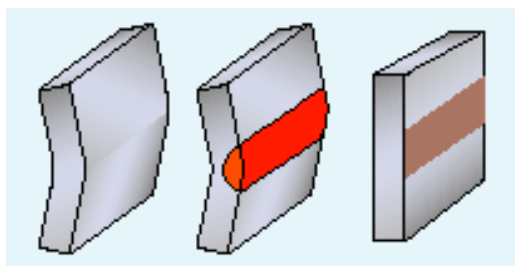


Figure 10.15 Localised heating to correct distortion.

This is achieved by locally heating the material to a temperature where plastic deformation will occur as the hot, low yield strength material tries to expand against the surrounding cold, higher yield strength metal. On cooling to room temperature the heated area will attempt to shrink to a smaller size than before heating. The stresses generated thereby will pull the component into the required shape (see above).

Local heating is, therefore, a relatively simple but effective means of correcting welding distortion. Shrinkage level is determined by size, number, location and temperature of the heated zones. Thickness and plate size determines the area of the heated zone. Number and placement of heating zones are largely a question of experience. For new jobs, tests will often be needed to quantify the level of shrinkage.

Spot, line, or wedge-shaped heating techniques can all be used in thermal correction of distortion.

Spot heating

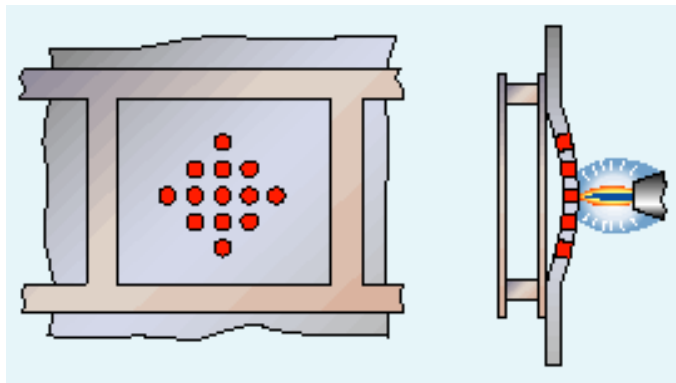


Figure 10.16 Spot heating for correcting buckling.

Spot heating is used to remove buckling, for example when a relatively thin sheet has been welded to a stiff frame. Distortion is corrected by spot heating on the convex side. If the buckling is regular, the spots can be arranged symmetrically, starting at the centre of the buckle and working outwards.

Line heating

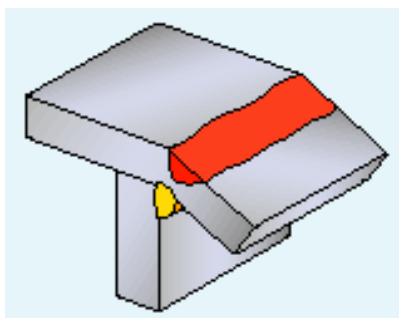


Figure 10.17 Line heating to correct angular distortion in a fillet weld.

Heating in straight lines is often used to correct angular distortion, for example, in fillet welds. The component is heated along the line of the welded joint but on the opposite side to the weld so the induced stresses will pull the flange flat.

Wedge-shaped heating

To correct distortion in larger complex fabrications it may be necessary to heat whole areas in addition to employing line heating. The pattern aims at shrinking one part of the fabrication to pull the material back into shape.

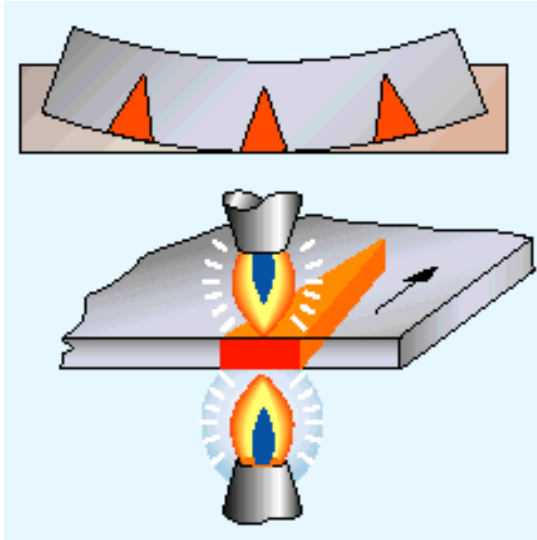


Figure 10.18 Use of wedge shaped heating to straighten plate.

Apart from spot heating of thin panels, a wedge-shaped heating zone should be used from base to apex and the temperature profile should be uniform through the plate thickness. For thicker section material, it may be necessary to use two torches, one on each side of the plate.

As a general guideline, to straighten a curved plate wedge dimensions should be:

- Length of wedge - two-thirds of the plate width.
- Width of wedge (base) - one sixth of its length (base to apex).

The degree of straightening will typically be 5mm in a 3m length of plate. Wedge-shaped heating can be used to correct distortion in a variety of situations, (see below):

- Standard rolled section, which needs correction in two planes a).
- Buckle at edge of plate as an alternative to rolling b).
- Box section fabrication, which is distorted out of plane c).

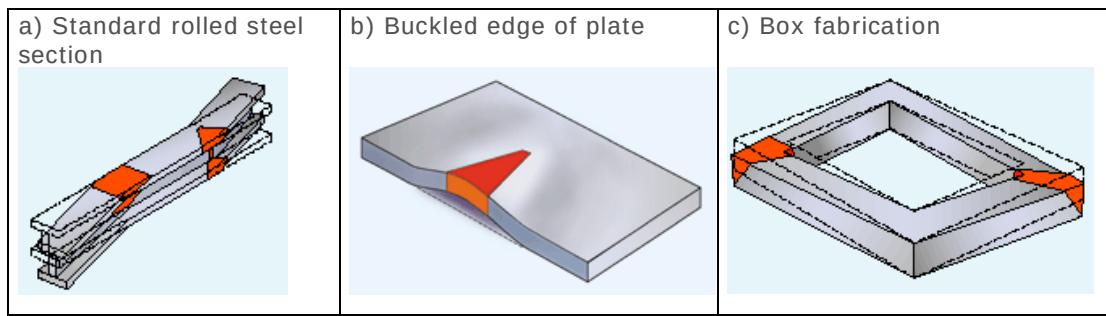


Figure 10.19 Wedge shaped heating to correct distortion.

General precautions

The dangers of using thermal straightening techniques are the risk of over-shrinking too large an area or causing metallurgical changes by heating to too high a temperature. As a general rule, when correcting distortion in steels the temperature of the area should be restricted to approximately to 600-650°C - dull red heat.

If the heating is interrupted, or the heat lost, the operator must allow the metal to cool and then begin again.

Best practice for distortion correction by thermal heating

The following should be adopted when using thermal techniques to remove distortion:

- Use spot heating to remove buckling in thin sheet structures.
- Other than in spot heating of thin panels, use a wedge-shaped heating technique.
- Use line heating to correct angular distortion in plate.
- Restrict the area of heating to avoid over-shrinking the component.
- Limit the temperature to 600-650°C (dull red heat) in steels to prevent metallurgical damage.
- In wedge heating, heat from the base to the apex of the wedge, penetrate evenly through the plate thickness and maintain an even temperature.

TWI

Residual Stress and Distortion

Section 10

Materials Joining and Engineering Technologies
Training and Examination Services

TWI

Residual Stress

Residual stresses are undesirable because

- They lead to distortions.
- They affect dimensional stability of the welded assembly.
- They enhance the risk of brittle fracture.
- They can facilitate certain types of corrosion.

Factors affecting residual stresses

- Parent material properties.
- Amount of restraint.
- Joint design.
- Fit-up.
- Welding sequence.

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Factors Affecting Residual Stress

Parent material properties

- Thermal expansion coefficient - the greater the value, the greater the residual stress.
- Yield strength - the greater the value, the greater the residual stress.
- Young's modulus - the greater the value (increase in stiffness), the greater the residual stress.
- Thermal conductivity - the higher the value, the lower the residual stress.

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Factors Affecting Residual Stress

Joint design

- Weld metal volume.
- Type of joint - butt vs. fillet, single vs. double side.

Amount of restraint

- Thickness - as thickness increase, so do the stresses.
- High level of restraint lead to high stresses.
- The lack of pre heat will increase stresses.

Fit-up

- Misalignment may reduce stresses in some cases.
- Root gap - increase in root gap increases shrinkage.

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Factors Affecting Residual Stress

Welding sequence

- Number of passes - every pass adds to the total contraction.
- Heat input - the higher the heat input, the greater the shrinkage.
- Travel speed - the faster the welding speed, the less the stress.
- Build-up sequence.

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Factors Affecting Residual Stress

Residual stresses

- Are a result of local plastic deformation.
- Are a result of non uniform heating and cooling ie welding.
- Are a result of non uniform heating, cooling, expansion and contraction.
- This is because the expansion and contraction can be obstructed by colder surrounding materials and also the mechanical properties of the material being welded.

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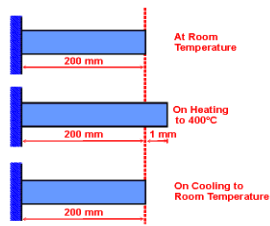


Nature of Residual Stress

Heating and cooling leads to expansions and contractions.

The material as shown can expand and contract freely without hindrance.

A welded joint does not react in this way!



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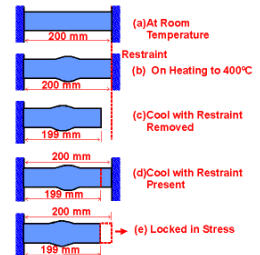


Residual Stress

If expansion is hindered, compressive stresses occur.

If on cooling shrinkage is obstructed, tensile stresses occur.

The overall result, Residual Stresses.

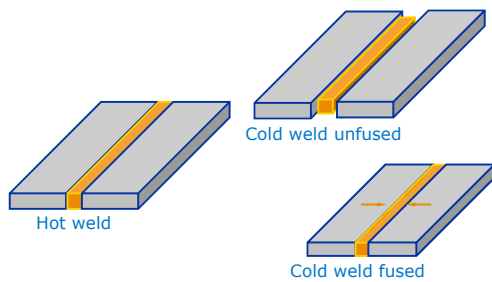


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Residual Stress

Origins of residual stress in welded joints



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Factors Affecting Residual Stress

Residual stresses

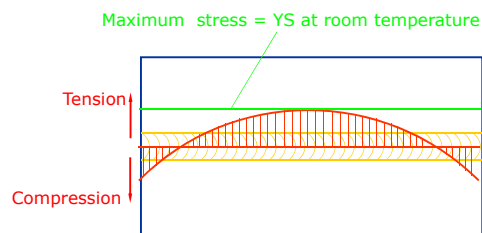
- Temperatures higher than 600°C, depending on the restraint, plastic deformation occurs (distortion).
- Temperatures lower than 600°C, depending on restraint, residual stresses occur because temperature not high enough to yield the material sufficiently.

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Types of Residual Stress

Longitudinal residual stress after welding



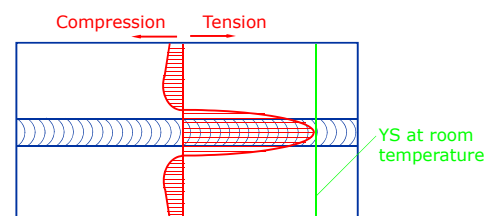
The longer the weld, the higher the tensile stress!

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Types of Residual Stress

Residual stress after welding



The higher the heat input the wider the tensile zone!

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Residual Stress

Reducing residual stresses

- The most effective way to reduce residual stresses is to post weld heat treat uniformly.
- The most effective method is to PWHT the whole member but this is not always possible.
- A controlled local, uniform PWHT usually reduces stresses by 75%.

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Residual Stress

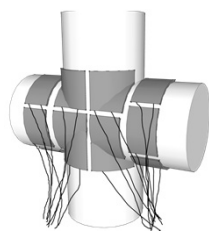
Post weld heat treatment

- Controlled ramp up to soak temperature so that complex items are heated uniformly and distortion does not take place.
- Held at soak temperature for approximately one hour for every 25mm of thickness.
- Controlled reduction of temperature.

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Heat Treatment Methods



Local heat treatment using electric heating blankets

Advantages

- Ability to vary heat.
- Ability to continuously maintain heat.

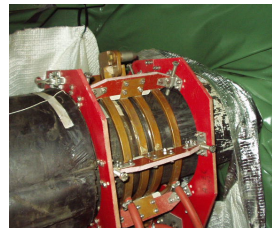
Disadvantages

- Elements may burn out or arc during heating.

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Heat Treatment Methods



HF local heat treatment

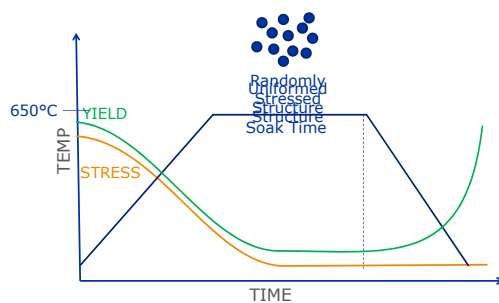
Advantages:

- High heating rates.
- Ability to heat a narrow band.

Disadvantages

- High equipment cost.
- Large equipment, less portable.

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Distortion

Factors affecting distortion

- Parent material properties.
- Amount of restraint.
- Joint design.
- Fit-up.
- Welding sequence.

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Factors Affecting Distortion

Parent material properties

- Thermal expansion coefficient - the greater the value, the greater the residual stress.
- Yield strength - the greater the value, the greater the residual stress.
- Thermal conductivity - the higher the value, the lower the residual stress.

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Factors Affecting Distortion

Welding sequence

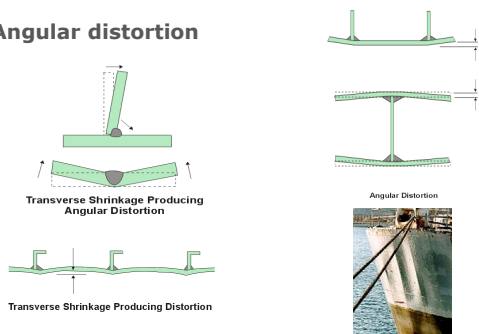
- Number of passes - every pass adds to the total contraction.
- Travel speed - the faster the welding speed, the less the stress.
- Build-up sequence.

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Types of Distortion

Angular distortion



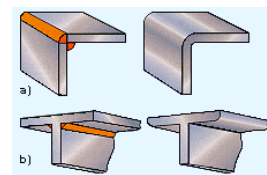
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Distortion Prevention

Distortion prevention by design

Consider eliminating the welding!!



- a) By forming the plate.
- b) By use of rolled or extruded sections.

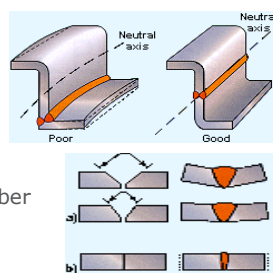
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Distortion Prevention

Distortion prevention by design

- Consider weld Placement.
- Reduce weld metal volume and/or number of runs.



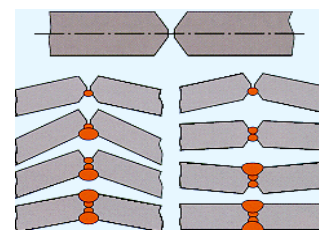
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Distortion Prevention

Distortion prevention by design

- Use of balanced welding.

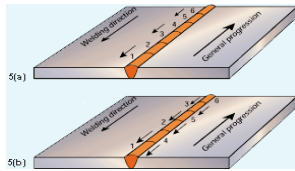


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Distortion Prevention

Distortion prevention by fabrication techniques



Control welding techniques by

- a) Back-step welding.
- b) Skip welding.

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Residual Stress and Distortion

You are currently employed as a Senior Welding Inspector on a fabricated steel structure.

The structure has many different joint configurations with a thickness range from 12.5mm up to 50mm.

All welding to be completed by either the SAW or MMA welding processes.

One of your main tasks is to ensure both stress and distortion is kept to a minimum.

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Question 1

Residual stresses would play a major part in which of the following

- a. HICC and brittle fracture
- b. Lamellar tearing and solidification cracking
- c. Fatigue and ductile failure
- d. Chevron cracking and hot cracking

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Question 2

Which of the following conditions would cause the greatest amount of distortion on this type of fabricated structure?

- a. A highly restrained joint during welding
- b. A joint, which is free to move during welding
- c. A joint, which would be subjected to the lowest heat input
- d. 2 options are correct

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Question 3

Which combination of factors will increase the level of distortion?

- a. High R_m , high thermal conductivity and low coefficient of expansion
- b. Low R_e , low thermal conductivity and high coefficient of expansion
- c. High yield, high UTS and low coefficient of expansion
- d. Low percentage Z, High percentage of Sulphur and Phosphorous

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Question 4

The fabrication contains materials of varying R_e values, generally which of the following would you expect to distort the most without control methods in place?

- a. Welded joints made from the highest R_e value materials
- b. Welded joints made from the lowest R_e value materials
- c. Welded joints that contain the highest residual stress
- d. 2 options are correct

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Question 5

Part of the fabrication contains a joint made from C/Mn steel welded to a 316L steel. Which of the following best applies when considering distortion?

- a. The C/Mn steel side of the joint will distort the most due to high thermal expansion
- b. The C/Mn steel side of the joint will distort the most due to low thermal conductivity
- c. The 316L side of the joint will distort the most due to high thermal conductivity
- d. The 316L side of the joint will distort the most due to low thermal conductivity

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Question 6

Which of the following are factors affecting distortion?

- a. Parent material properties
- b. Joint design/amount of restraint
- c. Heat input/welding sequence
- d. All options are correct

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Question 7

The fabricator approaches you on the best way to reduce distortion. The joint configuration, welding process, material type can't be changed. Which of the following could be applied to reduce distortion?

- a. Increase restraint and minimize the amount of weld beads deposited, heavier weld beads
- b. Reduce restraint and minimize the amount of weld beads deposited, heavier weld beads
- c. Increase restraint and maximize the amount of weld beads deposited, lighter weld beads
- d. Reduce restraint and increase the amount of weld beads deposited, heavier weld beads

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Question 8

Which of the following thickness and joint configurations would you expect to produce the highest amount of distortion?

- a. 25.5mm single V butt
- b. 50mm single U butt
- c. 50mm double U butt
- d. 25.5mm single J butt

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Question 9

After welding it is a requirement to conduct a PWHT on certain welded joints. On this welded structure what is the main purpose of this heat treatment?

- a. Normalising the material to increase the UTS value for the welded structure
- b. For hydrogen release, especially if a E8016 electrodes had been used for the welding of the joint.
- c. For stress relieving the welded joint
- d. To anneal and temper the weld metal

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Question 10

One of your inspectors asks you what would a typical PWHT temperature be, when applied to this fabrication. Which of the following would be the correct answer when taking into account the material thickness range stated on a C/Mn to C/Mn steel welded joint?

- a. Approximately 50°C above the upper critical limit of the material stated
- b. Between 600°C to 650°C
- c. Approximately 100°C lower than the lower critical limit of the material stated
- d. 2 options are correct

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Section 11

Weldability of Steels

11 Weldability of Steels

The term weldability simply means the ability to be welded and many types of steel that are weldable have been developed for a wide range of applications.

However, it is the ease or difficulty of making a weld with suitable properties and free from defects which determines whether steels are considered as having 'good weldability' or said to have poor weldability. A steel is usually said to have poor weldability if it is necessary take special precautions to avoid a particular type of imperfection. Another reason may be the need to weld within a very narrow range of parameters to achieve properties required for the joint.

11.1 Factors that affect weldability

A number of inter-related factors determine whether a steel is said to have good or poor weldability. These are:

- Actual chemical composition.
- Weld joint configuration.
- Welding process to be used.
- Properties required from the weldments.

For steels with poor weldability it is particularly necessary to ensure that:

- Welding procedure specifications give welding conditions that do not cause cracking but achieve the specified properties.
- Welders work strictly in accordance with the specified welding conditions.
- Welding inspectors regularly monitor welders to ensure they are working strictly in accordance the WPSs.

Having a good understanding of the characteristics, causes, and ways of avoiding imperfections in steel weldments should enable welding inspectors to focus attention on the most influential welding parameters when steels with poor weldability are being used.

11.2 Hydrogen cracking

During fabrication by welding, cracks can occur in some types of steel, due to the presence of hydrogen. The technical name for this type of cracking is hydrogen induced cold cracking (HICC) but it is often referred to by other names that describe various characteristics of hydrogen cracks:

- Cold cracking - cracks occur when the weld has cooled down.
- HAZ cracking - cracks tend to occur mainly in the HAZ.
- Delayed cracking - cracks may occur some time after welding has finished (possibly up to ~48h).
- Underbead cracking - cracks occur in the HAZ beneath a weld bead.

Although most hydrogen cracks occur in the HAZ, there are circumstances when they may form in weld metal.

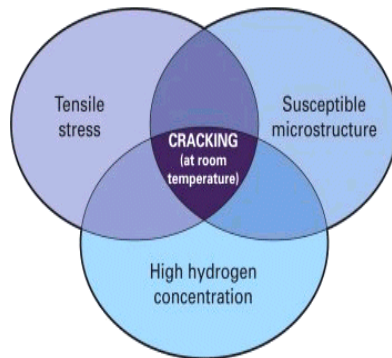
Figure 11.1 shows typical locations of HAZ hydrogen cracks.

Figure 11.2 shows hydrogen crack in the HAZ of a fillet weld.

11.2.1 Factors influencing susceptibility to hydrogen cracking

Hydrogen cracking in the HAZ of a steel occurs when **4 conditions exist at the same time**:

Hydrogen level	> 15ml / 100g of weld metal deposited
Stress	> 0.5 of the yield stress
Temperature	< 300°C
Susceptible microstructure	> 400HV hardness



These four conditions (four factors) are mutually interdependent so that the influence of one condition (its' active level) depends on how active the others three factors are.

11.2.2 Cracking mechanism

Hydrogen (H) can enter the molten weld metal when hydrogen containing molecules are broken down into H atoms in the welding arc.

Because H atoms are very small they can move about (diffuse) in solid steel and while weld metal is hot they can diffuse to the weld surface and escape into the atmosphere.

However, at lower temperatures H cannot diffuse as quickly and if the weldment cools down quickly to ambient temperature H will become trapped - usually the HAZ.

If the HAZ has a susceptible microstructure – indicated by being relatively hard and brittle, there are also relatively high tensile stresses in the weldment then H cracking can occur.

The precise mechanism that causes cracks to form is complex but H is believed to cause embrittlement of regions of the HAZ so that high-localised stresses cause cracking rather than plastic straining.

11.2.3 Avoiding HAZ hydrogen cracking

Because the factors that cause cracking are interdependent, and each need to be at an active level at the same time, cracking can be avoided by ensuring that at least one of the four factors is not active during welding.

Methods that can be used to minimise the influence of each of the four factors are considered in the following sub-sections.

Hydrogen

The principal source of hydrogen is moisture (H_2O) and the principal source of moisture is welding flux. Some fluxes contain cellulose and this can be a very active source of hydrogen.

Welding processes that do not require flux can be regarded as low hydrogen processes.

Other sources of hydrogen are moisture present in rust or scale, and oils and greases (hydrocarbons).

Reducing the influence of hydrogen is possible by:

- Ensuring that fluxes (coated electrodes, flux-cored wires and SAW fluxes) are low in H when welding commences.
- Low H electrodes must be either baked & then stored in a hot holding oven or supplied in vacuum-sealed packages.
- Basic agglomerated SAW fluxes should be kept in a heated silo before issue to maintain their as-supplied, low moisture, condition.
- Check the diffusible hydrogen content of the weld metal (sometimes it is specified on the test certificate).
- Ensuring that a low H condition is maintained throughout welding by not allowing fluxes to pick-up moisture from the atmosphere.
- Low hydrogen electrodes must be issued in small quantities and the exposure time limited; heated 'quivers' facilitate this control.
- Flux-cored wire spools that are not seamless should be covered or returned to a suitable storage condition when not in use.
- Basic agglomerated SAW fluxes should be returned to the heated silo when welding is not continuous.
- Check the amount of moisture present in the shielding gas by checking the dew point (must be below $-60^{\circ}C$).
- Ensuring that the weld zone is dry and free from rust/scale and oil/grease.

Tensile stress

There are always tensile stresses acting on a weld because there are always residual stresses from welding.

The magnitude of the tensile stresses is mainly dependent on the thickness of the steel at the joint, heat input, joint type, and size and weight of the components being welded.

Tensile stresses in highly restrained joints may be as high as the yield strength of the steel and this is usually the case in large components with thick joints and it is not a factor that can easily be controlled.

The only practical ways of reducing the influence of residual stresses may be by:

- Avoiding stress concentrations due to poor fit-up.
- Avoiding poor weld profile (sharp weld toes).
- Applying a stress-relief heat treatment after welding.
- Increasing the travel speed as practicable in order to reduce the heat input.
- Keeping weld metal volume to an as low level as possible.

These measures are particularly important when welding some low alloy steels that have particularly sensitivity to hydrogen cracking.

Susceptible HAZ microstructure

A susceptible HAZ microstructure is one that contains a relatively high proportion of hard brittle phases of steel - particularly martensite.

The HAZ hardness is a good indicator of susceptibility and when it exceeds a certain value a particular steel is considered to be susceptible. For C and C-Mn steels this hardness value is ~ 350HV and susceptibility to H cracking increases as hardness increases above this value.

The maximum hardness of an HAZ is influenced by:

- Chemical composition of the steel.
- Cooling rate of the HAZ after each weld run is made.

For C and C-Mn steels a formula has been developed to assess how the chemical composition will influence the tendency for significant HAZ hardening - the carbon equivalent value (CEV) formula.

The CEV formula most widely used (and adopted by IIW) is:

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

The CEV of a steel is calculated by inserting the material test certificate values shown for chemical composition into the formula. The higher the CEV of a steel the greater its susceptibility to HAZ hardening and therefore the greater the susceptibility to H cracking.

The element with most influence on HAZ hardness is carbon. The faster the rate of HAZ cooling after each weld run, the greater the tendency for hardening.

Cooling rate tends to increase as:

- Heat input decreases (lower energy input).
- Joint thickness increases (bigger heat sink).

Avoiding a susceptible HAZ microstructure (for C and C-Mn steels) requires:

- Procuring steel with a CEV that is at the low-end of the range for the steel grade (*limited scope of effectiveness*).
- Using moderate welding heat input so that the weld does not cool quickly (and give HAZ hardening).
- Applying pre-heat so that the HAZ cools more slowly (and does not show significant HAZ hardening); in multi-run welds, maintain a specific interpass temperature.

For low alloy steels, with additions of elements such as Cr, Mo and V, the CEV formula is not applicable and so must not be used to judge the susceptibility to hardening. The HAZ of these steels will always tend to be relatively hard regardless of heat input and pre-heat and so this is a 'factor' that cannot be effectively controlled to reduce the risk of H cracking. This is the reason why some of the low alloy steels have greater tendency to show hydrogen cracking than in weldable C and C-Mn steels, which enable HAZ hardness to be controlled.

Weldment at low temperature

Weldment temperature has a major influence on susceptibility to cracking mainly by influencing the rate at which H can move (diffuse) through the weld and HAZ. While a weld is relatively warm ($> \sim 300^{\circ}\text{C}$) H will diffuse quite rapidly and escape into the atmosphere rather than be trapped and cause embrittlement.

Reducing the influence of low weldment temperature (and the risk of trapping H in the weldment) can be effected by:

- Applying a suitable pre-heat temperature (typically 50 to $\sim 250^{\circ}\text{C}$).
- Preventing the weld from cooling down quickly after each pass by maintaining the preheat and the specific interpass temperature during welding.
- Maintaining the pre-heat temperature (or raising it to $\sim 250^{\circ}\text{C}$) when welding has finished and holding the joint at this temperature for a number of hours (minimum 2) to facilitate the escape of H (called **post-heat ***).

*Post-heat must not be confused with PWHT which is performed at a temperature $\geq \sim 600^{\circ}\text{C}$.

11.2.4 Hydrogen cracking in weld metal

Hydrogen cracks can form in steel weld metal under certain circumstances. The mechanism of cracking, and identification of all the influencing factors, is less clearly understood than for HAZ cracking but it can occur when welding conditions cause H to become trapped in weld metal rather than in HAZ. However it is recognised that welds in higher strength materials, thicker sections and using large beads are the most common areas where problems arise.

Hydrogen cracks in weld metal usually lie at 45° to the direction of principal tensile stress in the weld metal and this is usually the longitudinal axis of the weld (Figure 11.3). In some cases the cracks are of a V formation, hence an alternative name chevron cracking.

There are not any well-defined rules for avoiding weld metal hydrogen cracks apart from:

- Ensure a low hydrogen welding process is used.
- Apply preheat and maintain a specific interpass temperature.

BS EN 1011-2 entitled Welding – Recommendations for welding of metallic materials – Part 2: Arc welding of ferritic steels gives in Annex C practical guidelines about how to avoid H cracking. Practical controls are based principally on the application of pre-heat and control of potential H associated with the welding process.

11.3 Solidification cracking

The technically correct name for cracks that form during weld metal solidification is solidification cracks but other names are sometimes used when referring to this type of cracking.

- Hot cracking - they occur at high temperatures – while the weld is hot.
- Centreline cracking - cracks may appear down the centreline of the weld bead.
- Crater cracking - small cracks in weld craters are solidification cracks.

Because a weld metal may be particularly susceptible to solidification cracking it may be said to show hot shortness because it is short of ductility when hot and so tends to crack.

Figure 11.4 shows a transverse section of a weld with a typical centreline solidification crack.

11.3.1 Factors influencing susceptibility to solidification cracking

Solidification cracking occurs when three conditions exist at the same time:

- Weld metal has a susceptible chemical composition.
- Welding conditions used give an unfavourable bead shape.
- High level of restraint or tensile stresses present in the weld area.

11.3.2 Cracking mechanism

All weld metals solidify over a temperature range and since solidification starts at the fusion line towards the centreline of the weld pool, during the last stages of weld bead solidification there may be enough liquid present to form a weak zone in the centre of the bead. This liquid film is the result of low melting point constituents being pushed ahead of the solidification front.

During solidification, tensile stresses start to build-up due to contraction of the solid parts of the weld bead, and it is these stresses that can cause the weld bead to rupture. These circumstances result in a weld bead showing a centreline crack that is present as soon as the bead has been deposited.

Centreline solidification cracks tend to be surface breaking at some point in their length and can be easily seen during visual inspection because they tend to be relatively wide cracks.

11.3.3 Avoiding solidification cracking

Avoiding solidification cracking requires the influence of one of the factors responsible, to be reduced to an inactive level.

Weld metal composition

Most C and C-Mn steel weld metals made by modern steelmaking methods do not have chemical compositions that are particularly sensitive to solidification cracking.

However, these weld metals can become sensitive to this type of cracking if they are contaminated with elements, or compounds, that produce relatively low melting point films in weld metal.

Sulphur and copper are elements that can make steel weld metal sensitive to solidification cracking if they are present in the weld at relatively high levels. Sulphur contamination may lead to the formation of iron sulphides that remain liquid when the bead has cooled down as low as $\sim 980^{\circ}\text{C}$, whereas bead solidification starts at above 1400°C .

The source of sulphur may be contamination by oil or grease or it could be picked up from the less refined parent steel being welded by dilution into the weld.

Copper contamination in weld metal can be similarly harmful because it has low solubility in steel and can form films that are still molten at $\sim 1100^{\circ}\text{C}$.

Avoiding solidification cracking (of an otherwise non-sensitive weld metal) requires the avoidance of contamination with potentially harmful materials by ensuring:

- Weld joints are thoroughly cleaned immediately before welding.
- Any copper containing welding accessories are suitable/in suitable condition - such as backing-bars and contact tips used for GMAW, FCAW and SAW.

Unfavourable welding conditions

Unfavourable welding conditions are those that encourage weld beads to solidify so that low melting point films become trapped at the centre of a solidifying weld bead and become the weak zones for easy crack formation.

Figure 11.5 shows a weld bead that has solidified using unfavourable welding conditions associated with centreline solidification cracking.

The weld bead has a cross-section that is quite deep and narrow – a width-to-depth ratio $< \sim 2$ and the solidifying dendrites have pushed the lower melting point liquid to the centre of the bead where it has become trapped. Since the surrounding material is shrinking as a result of cooling, this film would be subjected to tensile stress, which leads to cracking.

In contrast, Figure 11.6 shows a bead that has a width-to-depth ratio that is $> > 2$. This bead shape shows lower melting point liquid pushed ahead of the solidifying dendrites but it does not become trapped at the bead centre. Thus, even under tensile stresses resulting from cooling, this film is self-healing and cracking is avoided.

SAW and spray-transfer GMAW are more likely to give weld beads with an unfavourable width-to-depth ratio than the other arc welding processes. Also, electron beam and laser welding processes are extremely sensitive to this kind of cracking as a result of the deep, narrow beads produced.

Avoiding unfavourable welding conditions that lead to centreline solidification cracking (of weld metals with sensitive compositions) may require significant changes to welding parameters, such as reducing the:

- Welding current (to give a shallower bead).
- Welding speed (to give a wider weld bead).

Avoiding unfavourable welding conditions that lead to crater cracking of a sensitive weld metal requires changes to the technique used at the end of a weld when the arc is extinguished, such as:

- For TIG welding, use a current slope-out device so that the current, and weld pool depth gradually reduce before the arc is extinguished (gives more favourable weld bead width-to-depth ratio). It is also a common practice to backtrack the bead slightly before breaking the arc or lengthen the arc gradually to avoid crater cracks.
- For TIG welding, modify weld pool solidification mode by feeding the filler wire into the pool until solidification is almost complete and avoiding a concave crater.
- For MMA, modify the weld pool solidification mode by reversing the direction of travel at the end of the weld run so that crater is filled.

11.4 Lamellar tearing

Lamellar tearing is a type of cracking that only occurs in steel plate or other rolled products underneath a weld.

Characteristics of lamellar tearing are:

- Cracks only occur in the **rolled products** eg plate and sections.
- Most common in C-Mn steels.
- Cracks usually form close to, but just outside, the HAZ.
- Cracks tend to lie parallel to surface of the material (and the fusion boundary of the weld), having a stepped aspect.

The above characteristics can be seen in Figure 11.7a.

11.4.1 Factors influencing susceptibility to lamellar tearing

Lamellar tearing occurs when two conditions exist at the same time:

- A susceptible rolled plate is used to make a weld joint.
- High stresses act in the through-thickness direction of the susceptible material (known as the short-transverse direction).

Susceptible rolled plate

A material that is susceptible to lamellar tearing has very low ductility in the through-thickness direction (short-transverse direction) and is only able to accommodate the residual stresses from welding by tearing rather than by plastic straining.

Low through-thickness ductility in rolled products is caused by the presence of numerous non-metallic inclusions in the form of elongated stringers. The inclusions form in the ingot but are flattened and elongated during hot rolling of the material.

Non-metallic inclusions associated with lamellar tearing are principally manganese sulphides and manganese silicates.

High through-thickness stress

Weld joints that are T, K and Y configurations end up **with a tensile residual stress component in the through-thickness direction**.

The magnitude of the through-thickness stress increases as the restraint (rigidity) of the joint increases. Section thickness and size of weld are the main influencing factors and it is in thick section, full penetration T, K and Y joints that lamellar tearing is more likely to occur.

11.4.2 Cracking mechanism

High stresses in the through-thickness direction, that are present as welding residual stresses, because the inclusion stringers to open-up (de-cohese) and the thin ligaments between individual de-cohesed inclusions then tear and produce a stepped crack.

Figure 11.11b shows a typical step-like lamellar tear.

11.4.3 Avoiding lamellar tearing

Lamellar tearing can be avoided by reducing the influence of one, or both, of the factors.

Susceptible rolled plate

BSEN 10164 (Steel products with improved deformation properties perpendicular to the surface of the product – Technical delivery conditions) gives guidance on the procurement of plate to resist lamellar tearing.

Resistance to lamellar tearing can be evaluated by means of tensile test pieces taken with their axes perpendicular to the plate surface (the through-thickness direction). Through-thickness ductility is measured as the % reduction of area (%R of A) at the point of fracture of the tensile test piece (Figure 11.8).

The greater the measured %R of A, the greater the resistance to lamellar tearing. Values in excess of ~20% indicate good resistance even in very highly constrained joints.

Reducing the susceptibility of rolled plate to lamellar tearing can be achieved by ensuring that it has good through-thickness ductility by:

- Using clean steel that has low sulphur content ($< \sim 0.015\%$) and consequently has relatively few inclusions.
- Procuring steel plate that has been subjected to through-thickness tensile testing to demonstrate good through-thickness ductility (as EN 10164).

Through-thickness stress

Through thickness stress in T, K and Y joints is principally the residual stress from welding, although the additional service stress may have some influence.

Reducing the magnitude of through-thickness stresses for a particular weld joint would require modification to the joint, in some way and so may not always be practical because of the need to satisfy design requirements. However, methods that could be considered are:

- Reducing the size of the weld by:
- Using a partial penetration butt weld instead of full-penetration.
- Using fillet welds instead of a full, or a partial pen butt weld (Figure 11.8).
- By applying a buttering layer of weld metal to the surface of a susceptible plate so that the highest through-thickness strain is located in the weld metal and not the susceptible plate (Figure 11.9).
- Changing the joint design – such as using a forged or extruded intermediate piece so that the susceptible plate does not experience through-thickness stress (Figure 11.10).

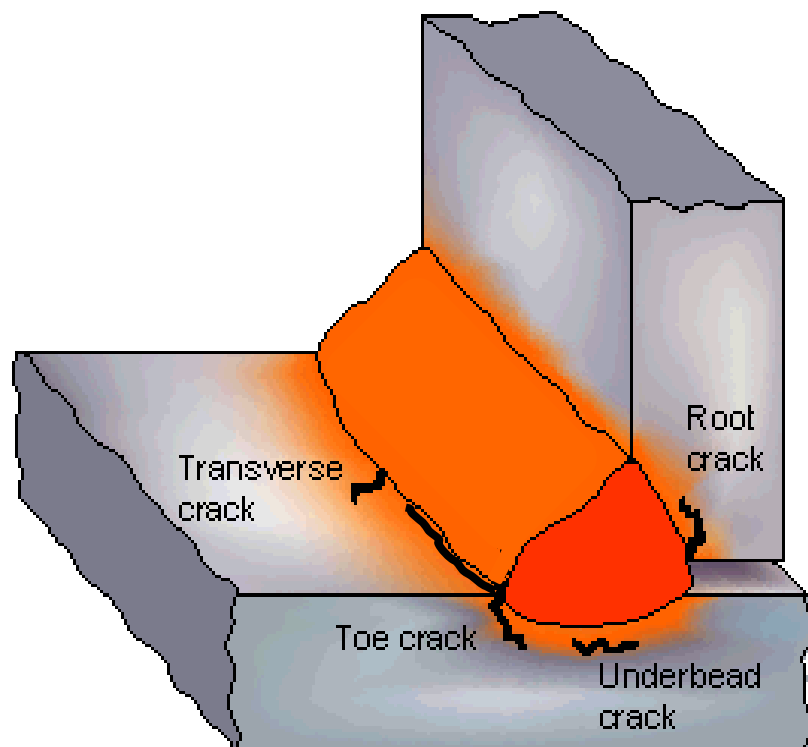


Figure 11.1 Typical locations of hydrogen induced cold cracks.



Figure 11.2 Hydrogen induced cold crack that initiated the HAZ at the toe of a fillet weld.

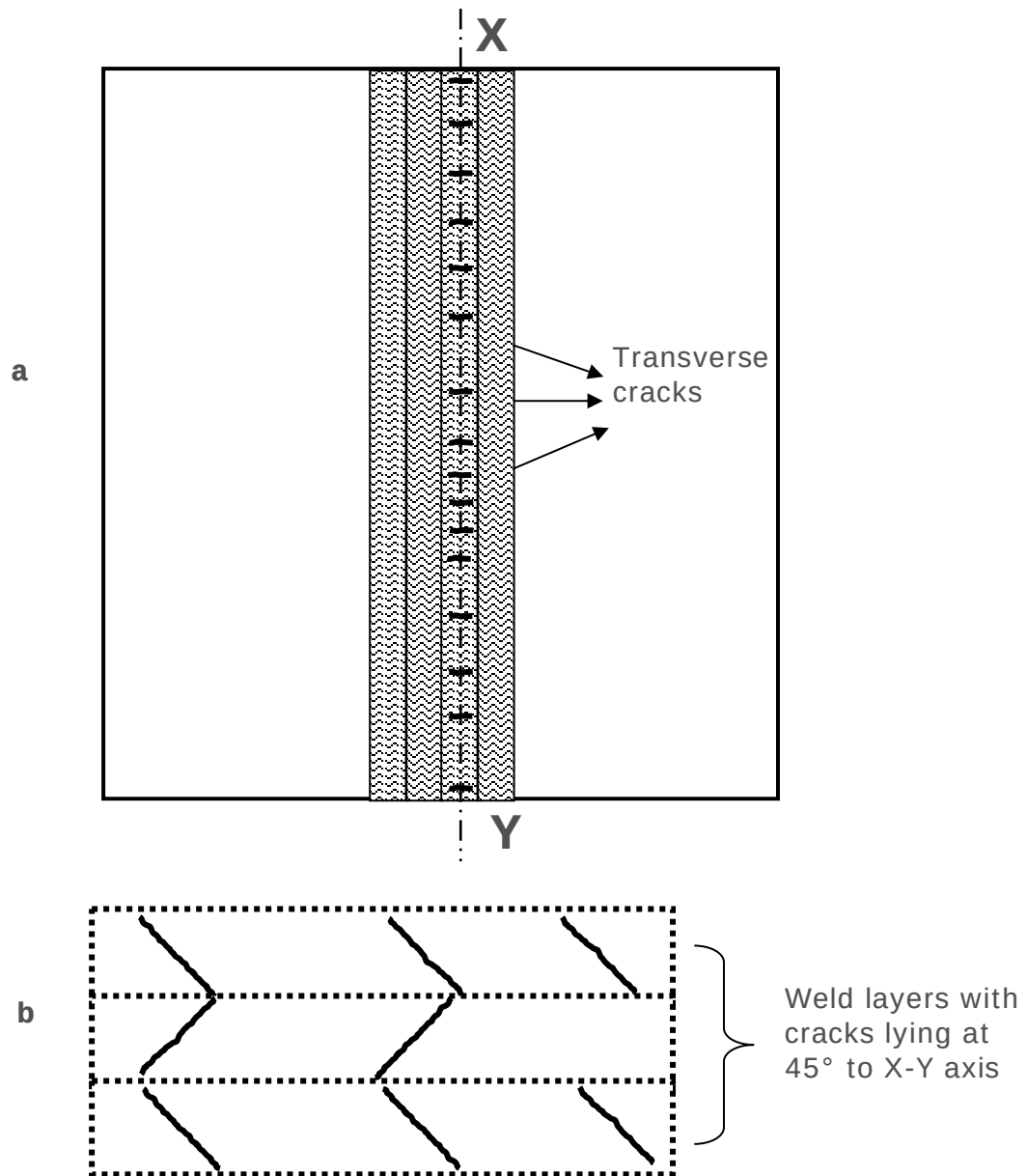


Figure 11.2a and b

- a** Plan view of a plate butt weld showing subsurface transverse cracks;
- b** Longitudinal section X-Y of the above weld showing how the transverse cracks actually lie at 45° to the surface. They tend to remain within an individual weld run and may be in weld several layers. Their appearance in this orientation has given rise to the name 'chevron' cracks (arrow shaped cracks).

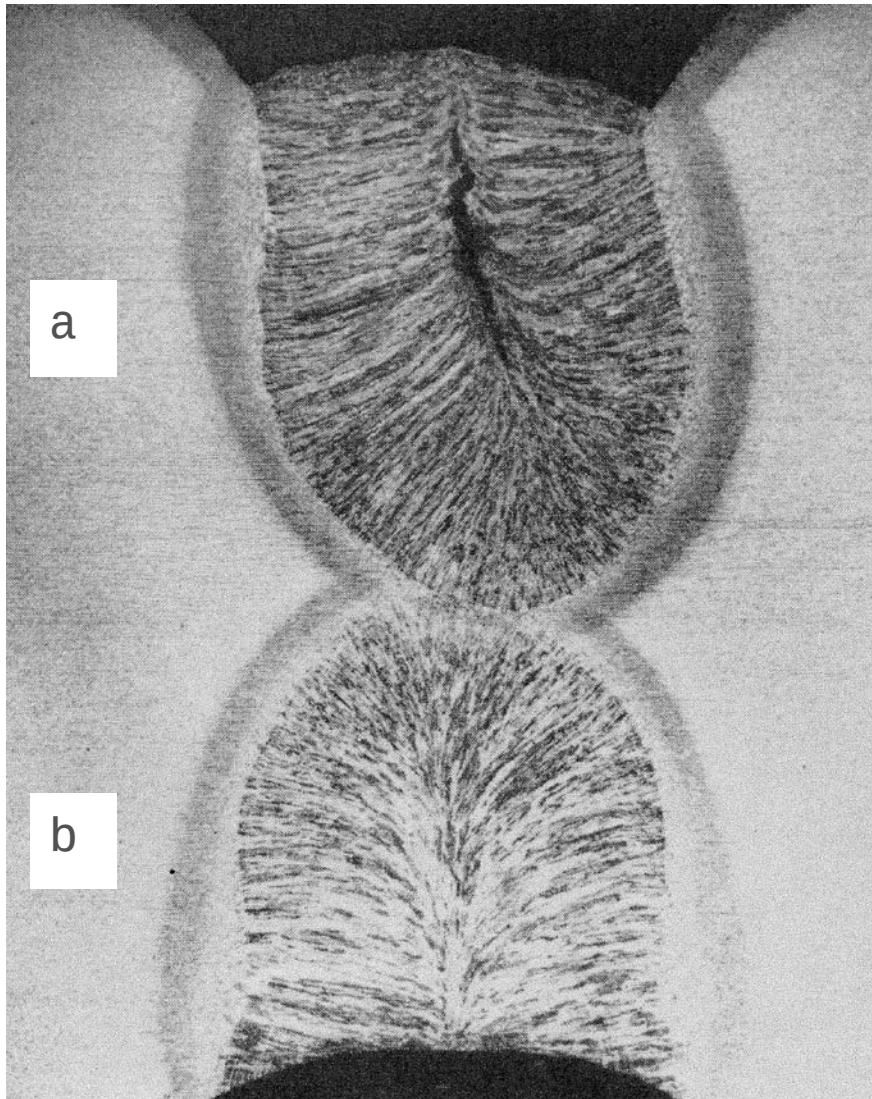


Figure 11.3

- a Solidification crack at the weld bead centre where columnar dendrites have trapped some lower melting point liquid**
- b The weld bead does not have an ideal shape but it has solidified without the dendrites meeting 'end-on' and trapping lower melting point liquid thereby resisting solidification cracking.**

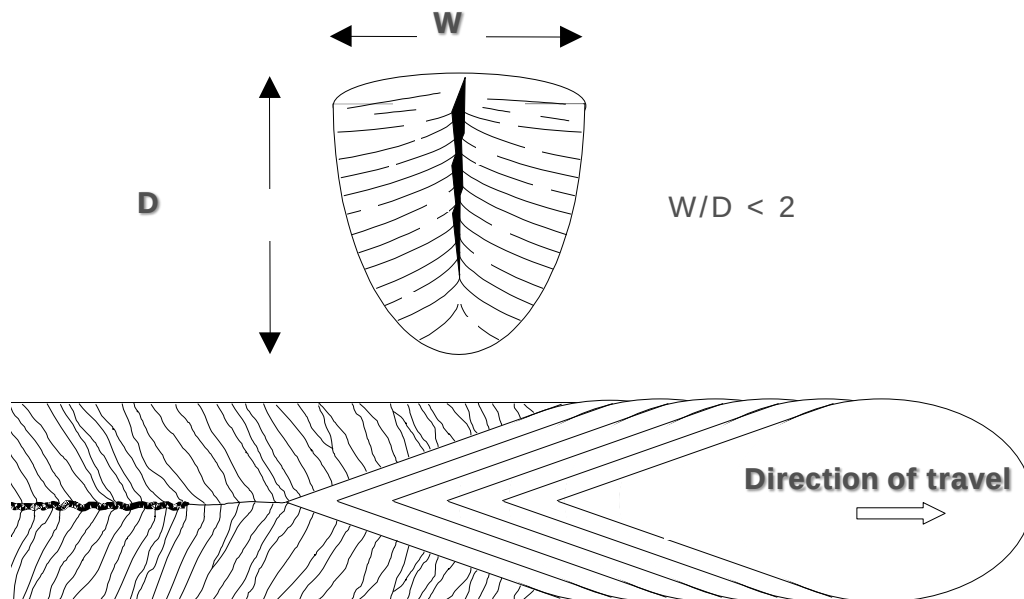


Figure 11.4 A weld bead with an unfavourable width-to-depth ratio.

This is responsible for liquid metal being pushed into the centre of the bead by the advancing columnar dendrites and becoming the weak zone that is ruptured.

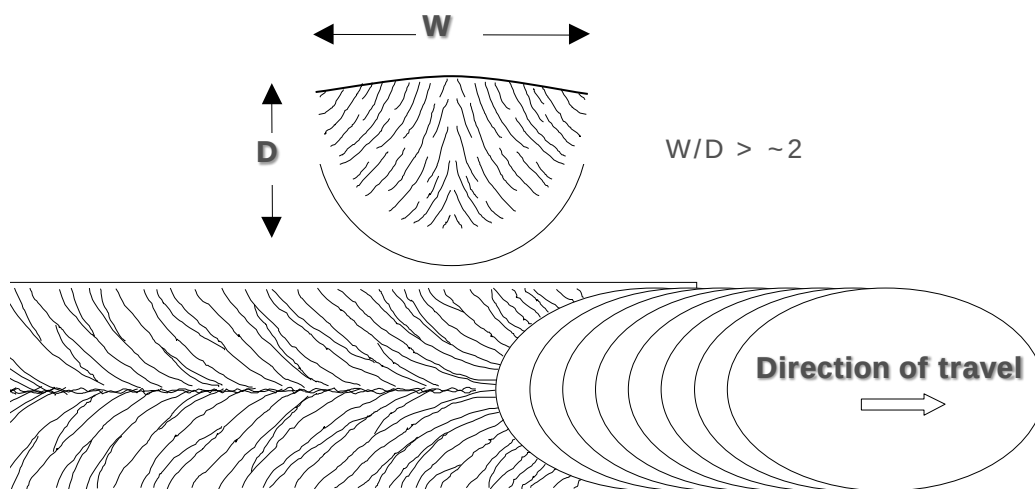


Figure 11.5 Weld bead with a favourable width-to-depth ratio.

The dendrites push the lowest melting point metal towards the surface at the centre of the bead centre and so it does not form a weak central zone.

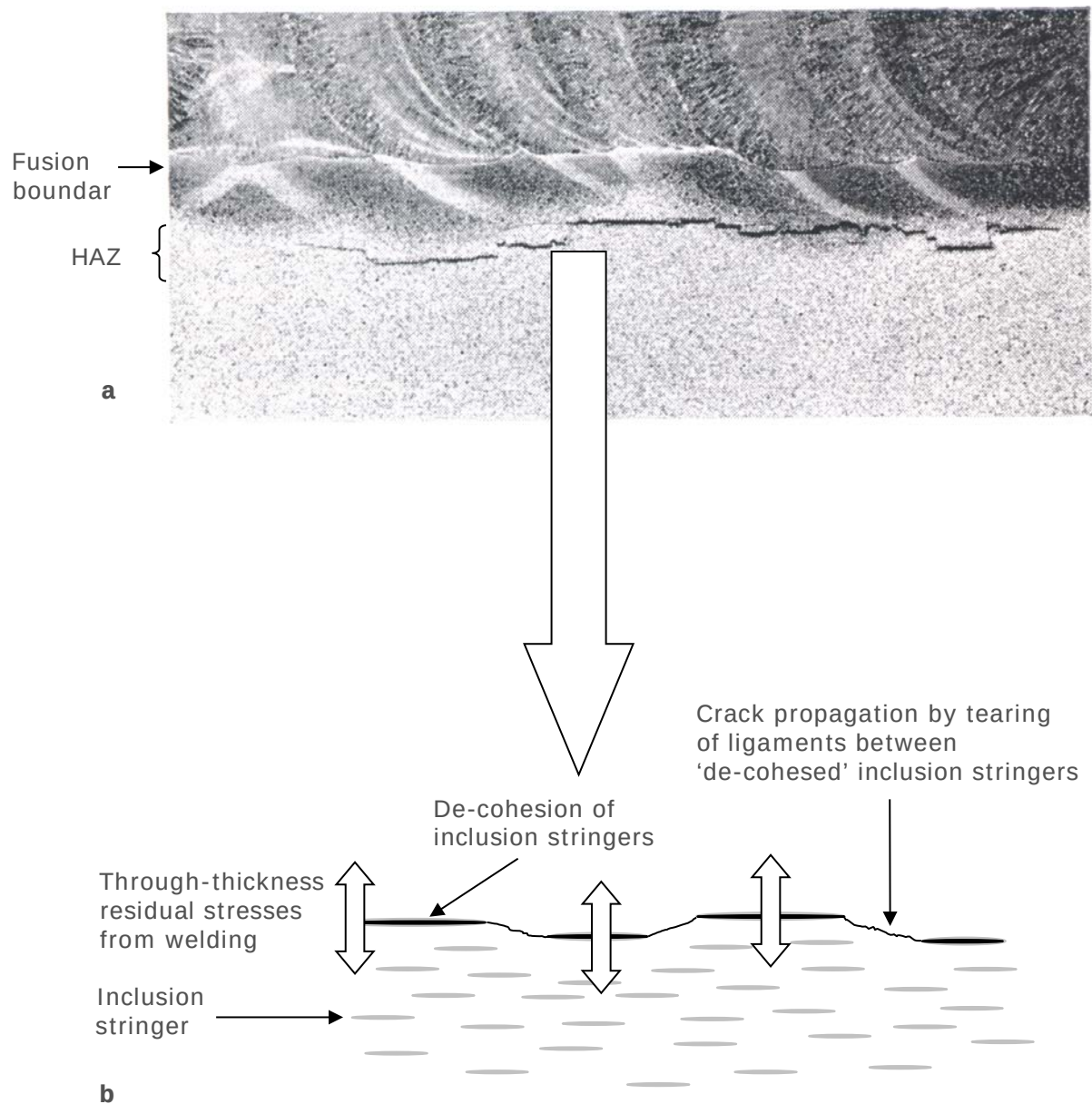


Figure 11.6

- a** Typical lamellar tear located just outside the visible HAZ;
- b** Step-like crack characteristic of a lamellar tear.

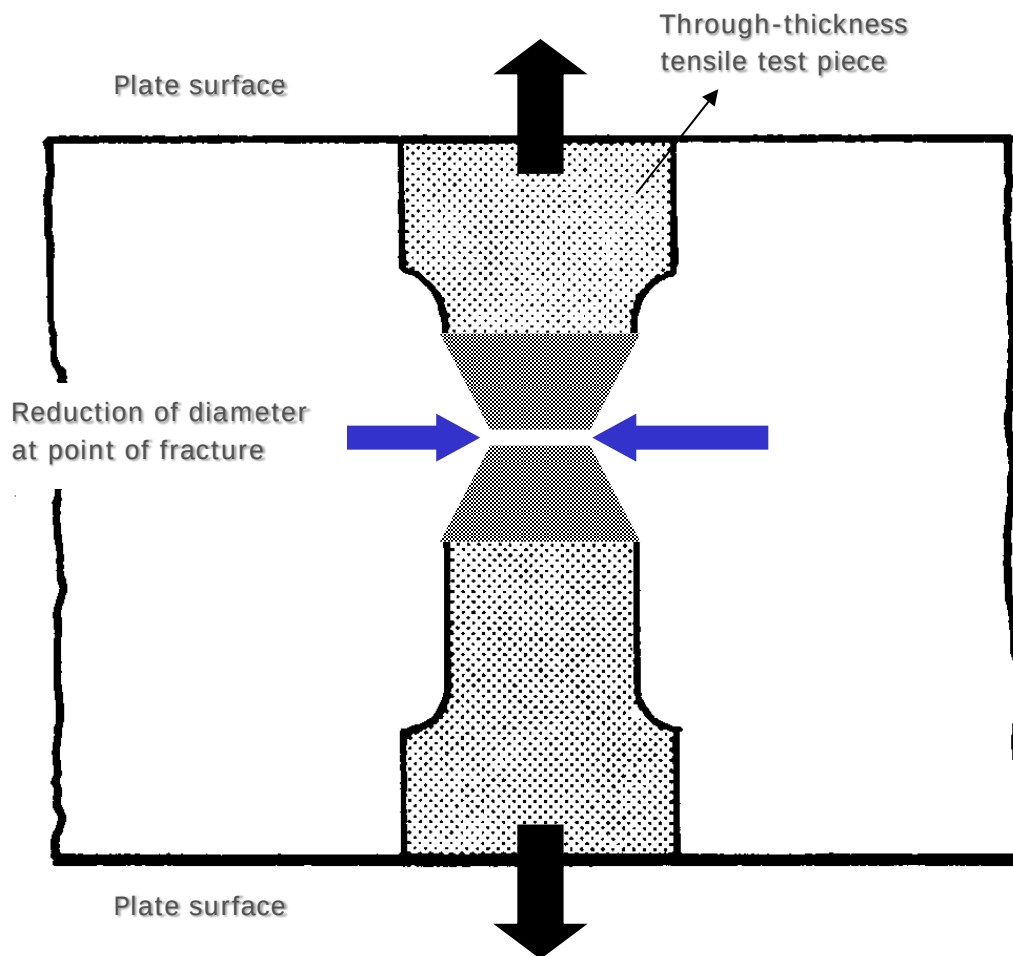


Figure 11.7 Round tensile test piece taken with its axis in the short-transverse direction (through thickness of plate) to measure the % R. of A. and assess the plate's resistance to lamellar tearing.

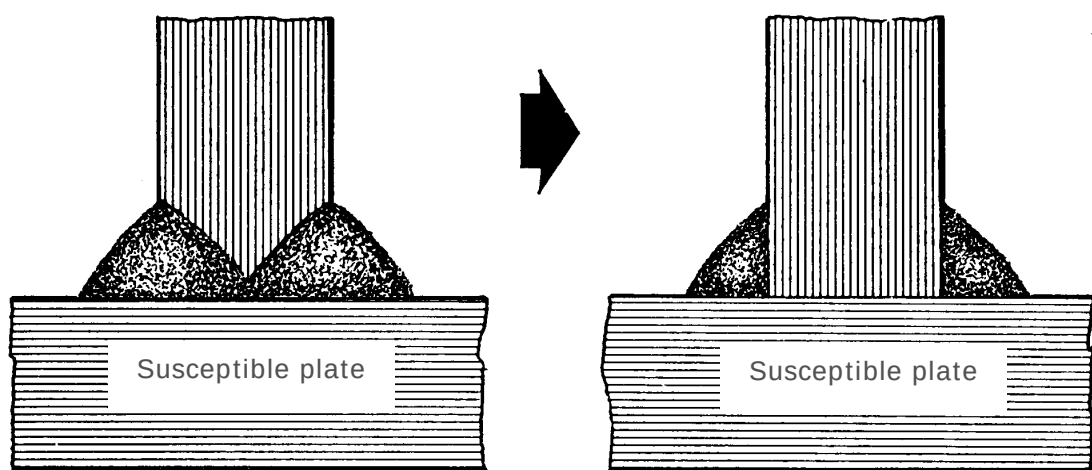


Figure 11.8 Reducing the effective size of a weld will reduce the through-thickness stress on the susceptible plate and may be sufficient to reduce the risk of lamellar tearing.

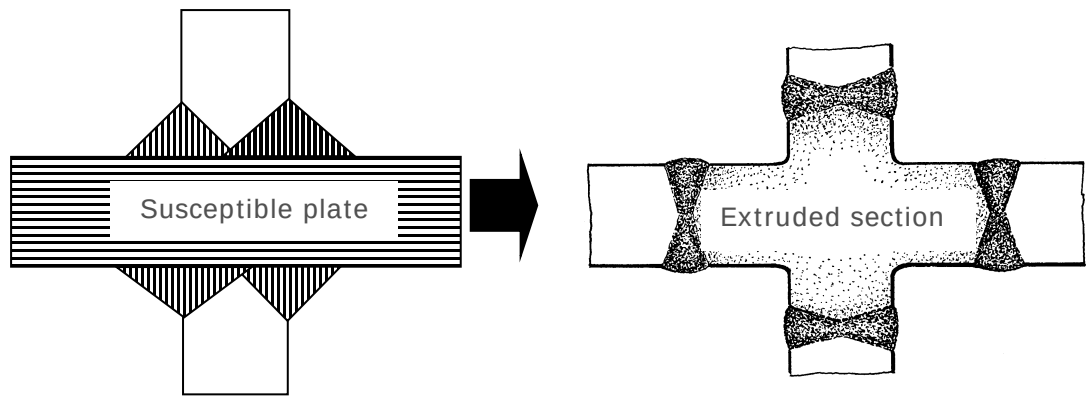


Figure 11.9 Lamellar tearing can be avoided by changing the joint design.

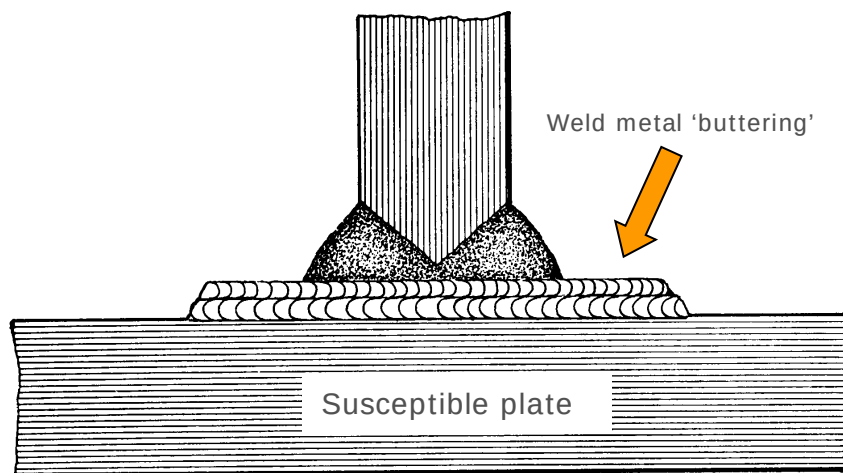


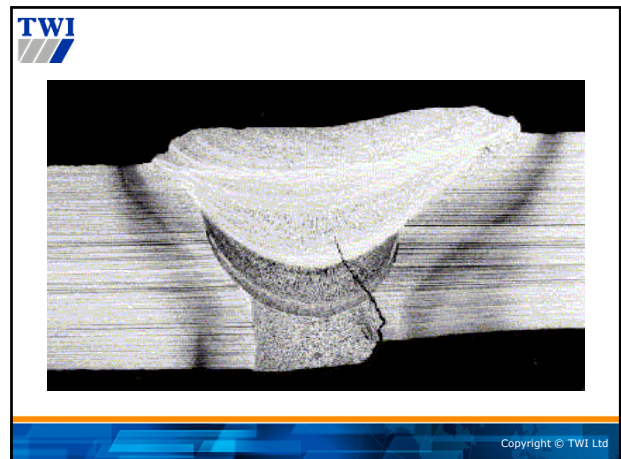
Figure 11.10 Two layers of weld metal (usually by MMA) applied to susceptible plate before the T-butt weld is made.

TWI

Weldability of Steels

Section 11

Materials Joining and Engineering Technologies
Training and Examination Services



TWI

What is Weldability?

"The ease with which a material, or materials can be welded to give an acceptable joint"
BS 499 - 1

Weldability = hardenability = susceptibility to cracking

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Weldability Problems

Weldability can pose problems for welders, inspectors & engineers.

Weldability is a measure of how easy (or how difficulty) it is to:

1. Obtain crack free welds.
2. Achieve adequate mechanical properties.

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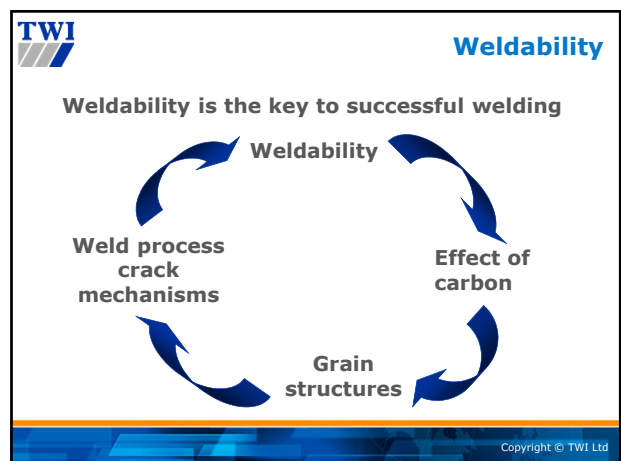
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Weldability Problems

Weldability problems can be overcome through understanding

- In order to produce a sound weld it is necessary to know and understand the material properties of the steels to be welded.

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The effect of carbon

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The Effect of Carbon

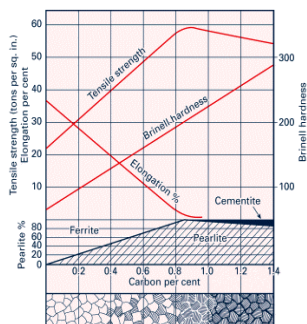
Steel is an alloy of iron and carbon (0.01 - 1.4%C). Plain Carbon Steels

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Carbon - The Key Element in Steel

It affects

1. Strength.
2. Hardness.
3. Ductility.



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The Effect of Carbon

Increase in tensile strength

Increase in hardness

0.1%

Increase in carbon

Decrease in elongation

1.4%

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The Effect of Carbon

Steel alloys can be divided into five main groups

1. Carbon steels.
2. Alloy steels.
3. Quenched & tempered steels.
4. Heat treatable low alloy steels.
5. Chromium molybdenum steels.

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The Effect of Carbon

Plain carbon steels come in three types

Low Carbon Steels	0.01 - 0.3%C
Medium Carbon Steels	0.3 - 0.6%C
High Carbon Steels	0.6 - 1.4%C

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Elements in steels

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Alloy Steels

Alloy steels contain iron and carbon plus other alloying elements to give the steel required mechanical & metallurgical properties.

Low alloy steels

Fe & C + Mn, Cr, Ni, Mo < 7% total

High alloy steels

Fe & C + Mn, Cr, Ni, Mo > 7% total

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Alloying Elements

Manganese (Mn) - Primary desulphuriser & secondary deoxidizer.

- Added to steels to reduce carbon.
- Affects strength & hardenability.

Silicon (Si) - Primary deoxidizer.

Aluminium (Al) - Grain refiner & tertiary deoxidizer.

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Alloying Elements

Molybdenum (Mo) - Improves creep resistance and temper embrittlement.

Chromium (Cr) - Improves hardness & resistance to wear. A major element in stainless steels to give corrosion resistance.

Nickel (Ni) - Improves ductility, strength & toughness. A key element in austenitic stainless steel to improve corrosion resistance from acids.

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Alloying Elements

Sulphur (S) - An impurity in steels. Harmful because it can cause 'hot shortness' - cracking during hot working.

Phosphorus (P) - An impurity in steels. Harmful in steels when over 0.05% because it can cause 'cold shortness' - cracking during cold working.

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Carbon Content Vs Carbon Equivalent

Carbon content

The actual amount of carbon in the steel.

Carbon Equivalent

The carbon content in relation to other alloying elements.

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

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TWI Carbon Content Vs Carbon Equivalent

Because Manganese has 1/6 of the effect on hardenability compared to one part Carbon.

∴ The formula can be shortened to:

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

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TWI Carbon Content Vs Carbon Equivalent

A steel contains 0.12%C and 1.3%Mn.

What is the carbon equivalent?

$$\begin{aligned} Ceq\% &= C + \frac{Mn}{6} \\ &= 0.12 + \frac{1.3}{6} \\ &= 0.12 + 0.216 \end{aligned}$$

$$Ceq = 0.336\%$$

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Key grain structures

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TWI Grain Structures

Grain structures in materials are influenced by

1. Elements in the material.
2. Temperature.
3. Cooling rate.

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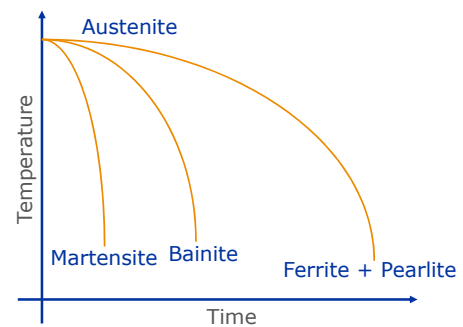
TWI Critical Cooling Rate

Critical cooling rate

The rate of cooling from the austenite region which determines the final grain structure.

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TWI Simplified Continuous Cooling Diagram



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Weld Process Crack Mechanisms

1. Hydrogen induced cold cracking (HICC).
2. Solidification cracking.
3. Lamellar tearing.
4. Re-heat cracking.

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TWI – Welding Inspection

Hydrogen Induced Cold Cracking (HICC)

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Hydrogen

Why can Hydrogen be a problem?

It can cause embrittlement in steel.

This is the process by which steels become brittle and fractures due to the introduction and subsequent diffusion of hydrogen into the metal.

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Factors for HICC

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Factors Affecting HICC

Factor	Quantum
Diffusible hydrogen content	> 15ml/100gm. Of weld metal for C steels. Can reduce with higher strength levels
Stress	> 0.5 of yield strength
Temperature	< 300C
Susceptible microstructure	Hardness > 400 VHN

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H₂ Access into Weld

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The Process of HICC

Hydrogen enters the weld via the welding arc.

Heat of the arc breaks down molecular hydrogen (H_2) into atomic hydrogen (H).

As weld cools hydrogen diffuses outwards into parent plate and atmosphere.

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The Process of HICC

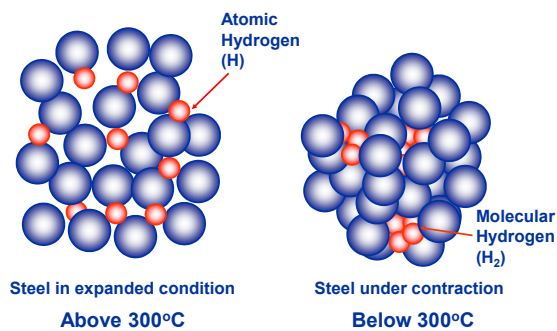
As the weld cools some hydrogen atoms can become trapped between grain boundaries as the lattice structure of the steel also contracts and changes.

Below 300°C hydrogen prefers to be in its molecular form (H_2) so individual atoms are attracted towards each other.

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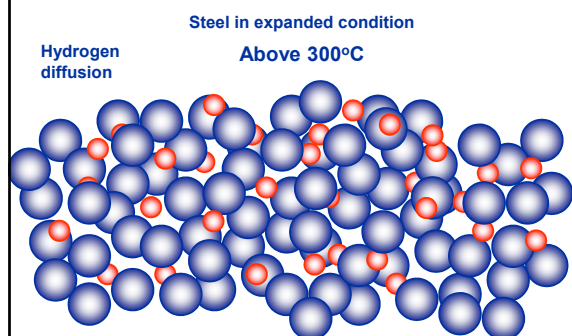
The Process of HICC



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The Process of HICC



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The Process of HICC

When hydrogen molecules exist in large numbers a lot of pressure is exerted, typically between 400 to 1400N/mm².

This can lead to cracking in susceptible microstructures where ductility is poor.

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Avoidance of HICC

1. Clean joint preparations.
2. Pre heat.
3. Use a low hydrogen welding process.
4. Use a multi pass welding technique.
5. Delay cooling rate.

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Avoidance of HICC

Below is a list of welding process in order of lowest hydrogen content (H_2 /100 grams of deposited weld metal).

TIG	< 3ml
MIG/MAG	< 5ml
MMA	< 5ml $\geq$ 60ml
SAW	< 10ml
FCAW	< 15ml

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Avoidance of HICC

Below is a list of hydrogen scales taken from BS EN 1011 with regards to 100 grams of weld metal deposited.

Scale	Hydrogen Content	
A	> 15 ml	
B	> 10 ml	< 15 ml
C	> 5 ml	< 10 ml
D	> 3 ml	< 5 ml
E	< 3 ml	

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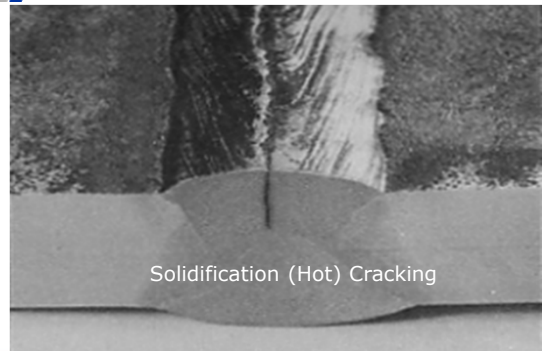
Avoiding HICC

Factor	Avoiding them
Diffusible hydrogen	Use LH consumable, process; cleaning; conditioning of consumables; weather conditions; use post heating; PWHT
Susceptible microstructure	Use preheat
Temperature	Maintain preheat, Use post heat
Stress	Reduce weld volume; balanced welding; skip, back step welding; pre-setting; automate; reduce number of runs; large weld beads; PWHT

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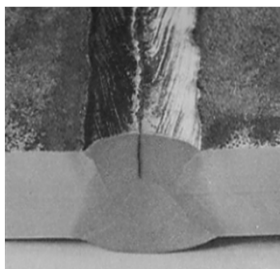
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Solidification (Hot) Cracking



Only occur in the weld metal.

Appear as straight lines along the centre line of the weld.

Can occur in the weld crater (star crack).

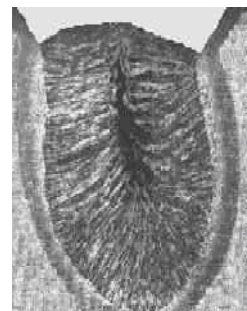
Usually readily visible.

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Factors for Solidification Cracking

1. High tensile stresses.
2. Sulphur.
3. Joint geometry.



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Solidification Cracking

- Sulphur in the parent material may dilute in the weld metal to form iron sulphides (low strength, low melting point compounds).
- During weld metal solidification, columnar crystals push still liquid iron sulphides in front to the last place of solidification, weld centerline .
- The bonding between the grains which are themselves under great stress. may now be very poor to maintain cohesion and a crack will result, weld centerline.

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Solidification Cracking

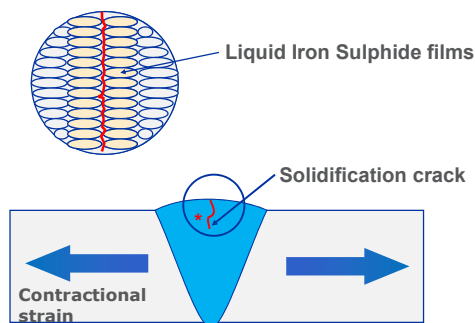
Factors for solidification cracking

- Columnar grain growth with impurities in weld metal (sulphur, phosphorus and carbon).
- The amount of stress/restraint.
- Joint design high depth to width ratios.
- Liquid iron sulphides are formed around solidifying grains.
- High contractional strains are present.
- High dilution processes are being used.
- There is a high carbon content in the weld metal.
- Most commonly occurring in sub-arc welded joints.

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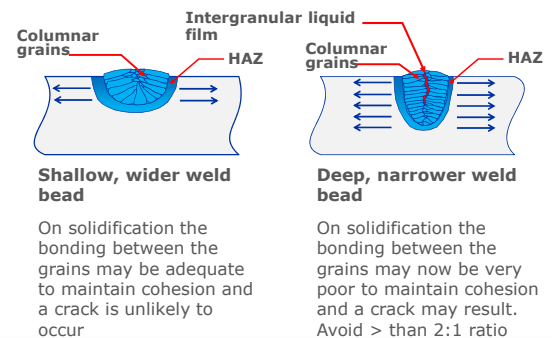
Solidification Cracking in Fe Steels



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Solidification Cracking



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Solidification Cracking

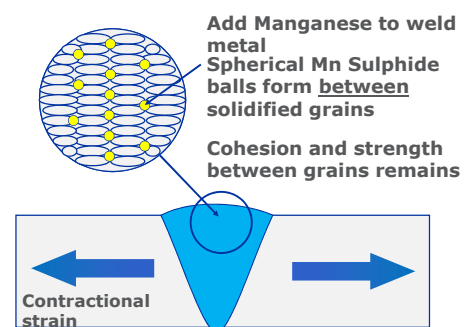
Precautions for controlling solidification cracking

- The use of high manganese and low carbon content fillers.
- Minimise the amount of stress/restraint acting on the joint during welding.
- The use of high quality parent materials, low levels of impurities (phosphorus and sulphur).
- Clean joint preparations contaminants (oil, grease, paints and any other sulphur containing product).
- Joint design selection depth to width ratios, avoid >2:1 ratio
- Avoid high welding speeds.

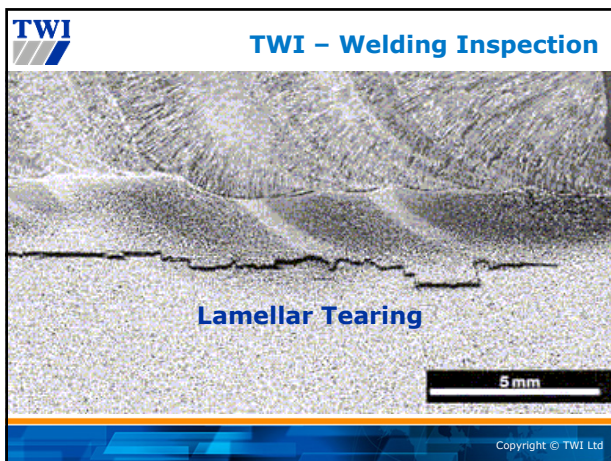
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Solidification Cracking



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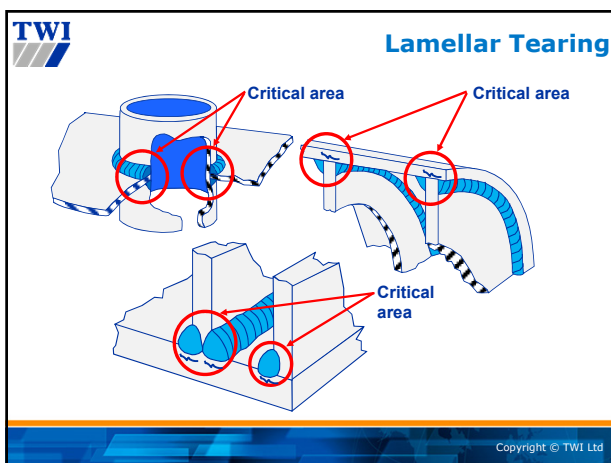
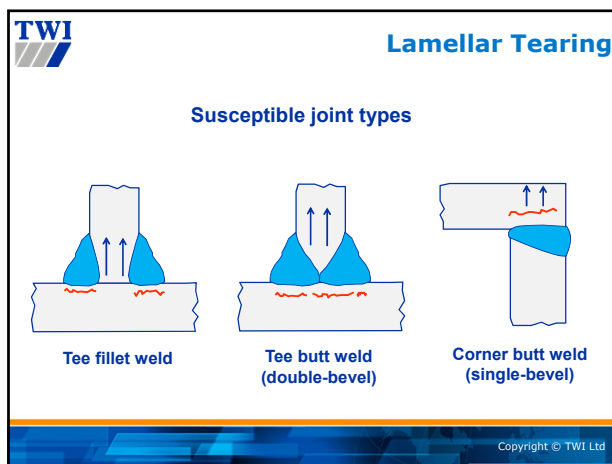
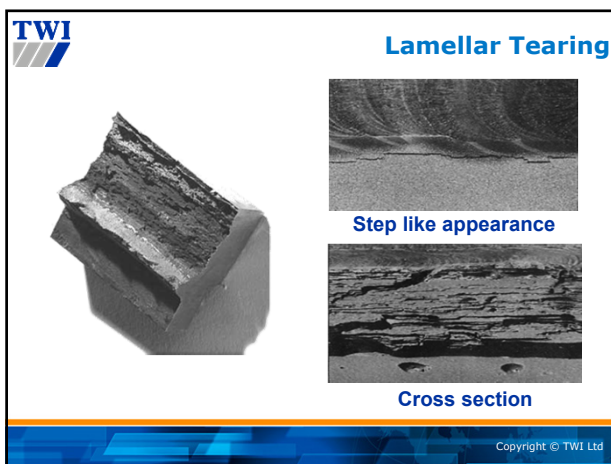


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Lamellar Tearing

- **Location:** Parent metal just below the HAZ.
- **Steel Type:** Any steel type possible.
- **Susceptible Microstructure:** Poor through thickness ductility.
- Lamellar tearing has a step like appearance due to the solid inclusions in the parent material (eg sulphides and silicates) linking up under the influence of welding stresses.
- Low ductile materials (often related to thickness) in the short transverse direction containing high levels of impurities are very susceptible to lamellar tearing.
- It forms when the welding stresses act in the short transverse direction of the material (through thickness direction).

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Lamellar Tearing

Factors for lamellar tearing to occur

- Low quality parent materials, high levels of impurities there is a high sulfur content in the base metal.
- Joint design, direction of stress 90 degrees to the rolling direction, the level of stress acting across the joint during welding.
- **Note!** very susceptible joints may form lamellar tearing under very low levels of stress.
- High contractional strains are through the short transverse direction.
- There is low through thickness ductility in the base metal.
- There is high restraint on the work.

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Lamellar Tearing

Assessment of susceptibility to lamellar tearing:

- Carry out through thickness tensile test.
- Carry out cruciform welded tensile test.

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Lamellar Tearing

Precautions for controlling lamellar tearing

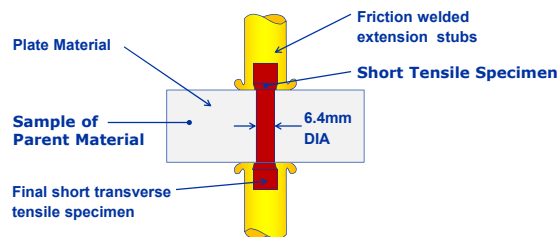
- The use of high quality parent materials, low levels of impurities.
- The use of buttering runs.
- A gap can be left between the horizontal and vertical members enabling the contraction movement to take place.
- Joint design selection.
- Minimise the amount of stress/restraint acting on the joint during welding.
- Hydrogen precautions.

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Short Tensile (Through Thickness) Test

The short tensile test or through thickness test is a test to determine a materials susceptibility to lamellar tearing



The results are given as a STRA v Short Transverse Reduction in Area

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Methods of avoiding lamellar tearing:*

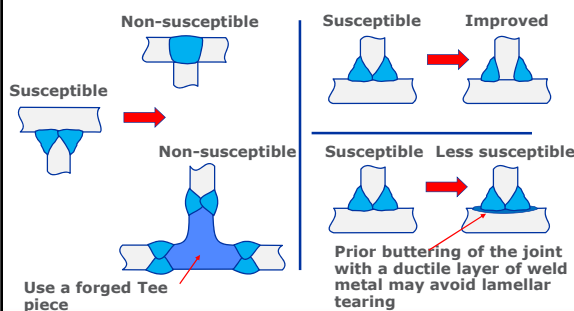
- 1 Avoid restraint*.
- 2 Use controlled low sulfur plate*.
- 3 Grind out surface and butter*.
- 4 Change joint design*.
- 5 Use a forged T piece (critical applications)*.

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Lamellar Tearing

Modifying a Tee joint to avoid lamellar tearing

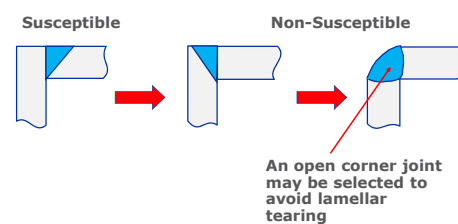


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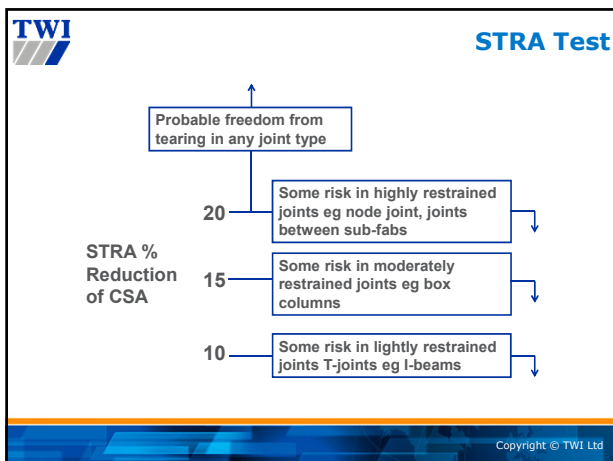


Lamellar Tearing

Modifying a corner joint to avoid lamellar tearing



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TWI **Weldability**

You are working as a Senior Welding Inspector during the fabrication and welding of a top side module, the module is fabricated from C/Mn steel maximum CE value of 0.46%.

Certain sections are fabricated from universal beams with thicknesses ranging from 12.5 to 50mm thickness, other sections are fabricated from steel plate again ranging from 12.5 mm to 50mm thickness.

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TWI **Question 1**

One of your inspectors suggests to you that lamellar tearing may have occurred in a single bevel butt joint. Would you agree with this comment?

- No, this defect can only occur in single v butt welds
- No, this type of defect will only occur in C/Mn steels with a CE value >0.48%
- Yes, this defect is possible in a single bevel butt, but it would require RT for clarification
- All options are incorrect

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TWI **Question 2**

You notice from the WPS on certain joints a pre heat of 150°C is required, on other joints the preheat is only 75°C. Why do you think some joints require more pre heat than others?

- This would be due to the different thickness of materials being used and the increased chances of solidification cracking
- This would be due to the different thickness of materials being used and the increased chances of hydrogen cracking
- This would be due to the fact that some welders require more preheat than others as it increases penetration
- All options are incorrect; it's due to lamellar tearing in thicker materials

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TWI **Question 3**

One of your inspectors suggests to you that the pre heat temperatures are too low to prevent hydrogen cracking occurring. Which of the following combinations are correct for determining a correct pre heat temperature to be applied prior to welding?

- Material thickness, joint design, the amount of hydrogen and welding process
- Material thickness, the amount of stress, hydrogen content and material type
- Material type and thickness, hydrogen scale and heat input
- The amount of stress, welding process, hydrogen content and material type

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TWI **Question 4**

One of your inspectors asks you what are the main factors affecting hydrogen cracking. Which of the following would be your best reply?

- Temperature, the amount of stress, molecular hydrogen and material composition
- Material thickness, atomic hydrogen, material composition and the amount of stress
- Sulphur content >0.03%, hydrogen content > 15ml, the amount of stress and material composition
- All options have insufficient information given

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Question 5

During visual inspection one of your inspectors detects a longitudinal crack along the weld centerline approximately 100mm in length. Which of the following would be reasons for the occurrence of this type of crack?

- a. Sulphur contents and manganese contents too low
- b. Sulphur contents too high, manganese contents too low
- c. Sulphur contents too low, manganese contents too high
- d. All options would cause this type of cracking

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Question 6

One of your welding inspectors informs you that during welding one of the welders is using an excessive long arc length. Which of the following issues could be caused by this situation?

- a. An increase in hydrogen content in the weld
- b. An increased risk of carbide precipitation occurring
- c. An increased risk of solidification cracking occurring
- d. An increased risk of lamellar tearing occurring after welding.

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Question 7

When inspecting the material certificates you notice some of the materials are classified as Z steels. What does this relate to?

- a. All these materials when welded will be free from solidification issues/cracking
- b. All these materials will have a guaranteed minimum UTS value of 500N/mm², this will help prevent the formation of hydrogen cracking
- c. All these materials will have a probable freedom from lamellar tearing when welded
- d. All these materials have properties of zero ductility

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Question 8

Which of the following could be used to prevent the formation of hydrogen cracking?

- a. The use of E8018 electrodes in standard packaging
- b. The use of E8010 electrodes, baked to 350°C prior to use to remove moisture
- c. The use of E6012 electrodes, used in a dried condition will give a lower UTS value which will give an increased elongation value
- d. All options are incorrect

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Question 9

One of your inspectors suggests increasing the restraint on all single V butt joints to reduce distortion. Which of the following may have detrimental affect of this?

- a. An increase risk of solidification cracking and lamellar tearing
- b. An increased risk of solidification and hydrogen cracking
- c. An increased risk of weld decay and hydrogen cracking
- d. All options are correct

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Question 10

During the inspection of the materials prior to fabrication one of the NDT inspection personnel reports back to you that he has detected lamellar type defects running in the center of the parent plate, sub-surface. Which of the following is correct?

- a. The defects detected would most likely be plate laminations and definitely not lamellar tearing
- b. Lamellar tearing does not happen sub surface, it is a surface breaking cracking mechanism
- c. If its been located in the center of the plate then it would most likely be solidification cracking
- d. NDT does not locate lamellar tearing it requires through thickness ductility testing to locate it when present

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Section 12

Weld Fractures

12 Weld Fractures

Welds may suffer three different fracture mechanisms:

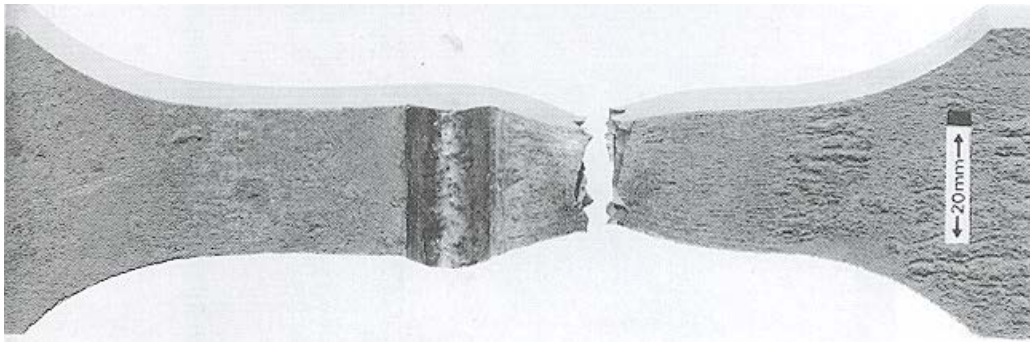
- Ductile.
- Brittle.
- Fatigue.

Often a complete fracture of a weldment will be a combination of fracture types eg initially fatigue followed by final ductile fracture.

12.1 Ductile fractures

Occur in instances where the strength and the cross-sectional area of the material are insufficient to carry the applied load.

Such fractures are commonly seen on material and welding procedure tensile test specimens where failure is accompanied by yielding, stretching and thinning as shown below.



The fracture edges are at 45° to the applied load and are known as shear lips.

12.2 Brittle fracture

Is a fast, unstable type of fracture which can lead to catastrophic failure.

The phenomenon was first identified during World War 2 when many Liberty Ships broke in two for no apparent reason. Since that time many brittle failures have occurred in bridges, boilers, pressure vessels etc sometimes with loss of life and always with expensive damage.

The risk of brittle fracture increases;

- As the temperature (ambient or operational) decreases.
- With the type and increasing thickness of the material.
- Where high levels of residual stresses are present.
- In the presence of notches.
- Increased strain rate ie speed of loading.

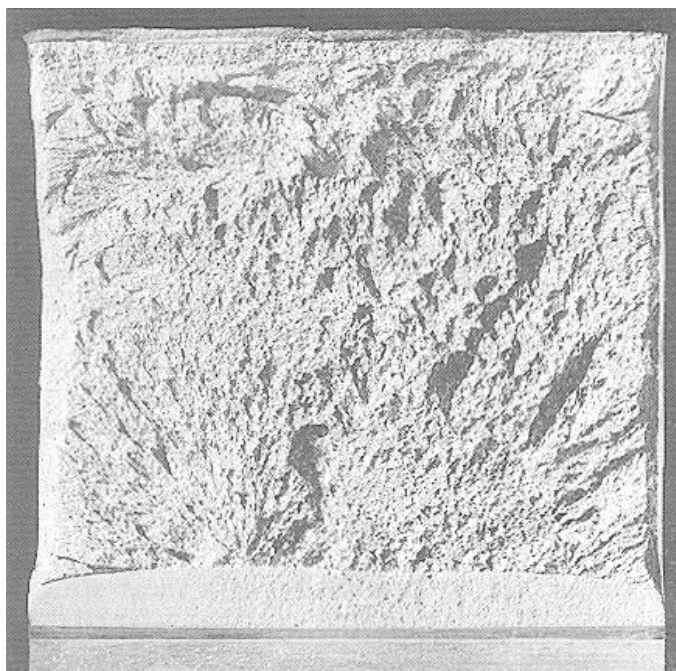


Courtesy of Douglas E. Williams, P.E., Welding Handbook, Vol.1, Ninth Edition, reprinted by permission of the American Welding Society.

Effect of notch on a tensile specimen.

Distinguishing features of a brittle fracture are:

- Surface is flat and at 90° to the applied load.
- Will show little or no plastic deformation.
- The surface will be rough and may be crystalline in appearance.
- May show chevrons which will point back to the initiation source.



Brittle fracture surface on a CTOD test piece.

12.3 Fatigue fracture

Fatigue fractures occur in situations where loading is of a cyclic nature and at stress levels well below the yield stress of the material.

Typically fatigue cracks will be found on bridges, cranes, aircraft and items affected by out of balance or vibrating forces.

Initiation takes place from stress concentrations such as changes of section, arc- strikes, toes of welds. Even the best designed and made welds have some degree of stress concentration.

As fatigue cracks take time firstly to initiate then to grow, this slow progression allows such cracks to be found by regular inspection schedules on those items known to be fatigue sensitive.

The growth rate of fatigue cracks is dependant on the loading and the number of cycles. It is not time dependant

Fatigue failures are not restricted to any one type of material or temperature range. Stress-relief has little effect upon fatigue life.

Structures known to be at risk of fatigue failure are usually designed to codes that acknowledge the risk and lays down the rules and calculations to predict its design life.



Typical fatigue fracture in a T joint.

Identifying features of fatigue fracture are:

- Very smooth fracture surface, although may have steps due to multiple initiation points.
- Bounded by curved crack front.
- Bands may be visible indicating crack progression.
- Initiation point opposite curve crack front.
- Surface at 90° to applied loading.

Fatigue cracks sometimes stop of their own accord if the crack runs into an area of low stress. On the other hand they may grow until the remaining cross-section is insufficient to support the applied loads. At this point final failure will take place by a secondary mechanism ie ductile or brittle.

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Weld Fractures

Section 12

Materials Joining and Engineering Technologies
Training and Examination Services

TWI

Fracture Mechanisms

- Ductile fracture.
- Brittle fracture.
- Fatigue fracture.

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Fracture Mechanisms

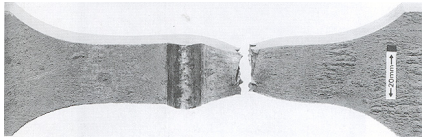
Ductile Fracture

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Ductile Fracture

Ductile (overload) fracture appears when yielding and deformation precedes failure



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Ductile Fracture

Ductile fracture distinguish features

- It is the result of overloading
- Evidence of gross yielding or plastic deformation
- The fracture surface is rough and torn
- The surface shows 45° shear lips or have surfaces inclined at 45° to the load direction (because maximum shear plane is at 45° to the load!)

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Fracture Mechanisms

Brittle Fracture

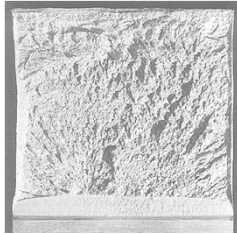
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Brittle Fracture

Brittle fracture

It is a fast, unstable type of fracture.



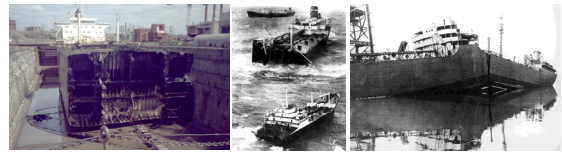
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Brittle Fracture

Brittle fracture

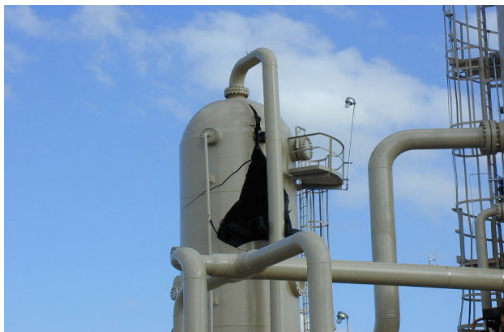
It is a fast, unstable type of fracture.



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Brittle Fracture



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Brittle Fracture



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Brittle Fracture



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Brittle Fracture

Brittle fracture distinguish features

- There is little or no plastic deformation before failure
- The crack surface may show chevron marks pointing back to the initiation point
- In case of impact fracture, the surface is rough but not torn and will usually have a crystalline appearance
- The surface is normally perpendicular to the load

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Brittle Fracture

Factors affecting brittle fracture

- Temperature (transition curve, convergence of YS and UTS as the temperature is reduced)
- Crystalline structure (b.c.c. vs. f.c.c.)
- Material toughness
- Residual stress
- Strain rate (YS increase but UTS remain constant)
- Material thickness (restrain due to surrounding material)
- Stress concentrations/weld defects

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Brittle Fracture

Causes for brittle fracture

- Presence of weld defects (poor quality)
- Poor toughness in parent material (wrong choice)
- Poor toughness in HAZ (to high heat input)
- High level of residual stress (no PWHT, wrong design)

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Fracture Mechanisms

Fatigue Fracture

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Fatigue Fracture

Fatigue fracture distinguish features

- Crack growth is slow.
- It initiate from stress concentration points.
- Load is considerably below the design or yield stress level.
- The surface is smooth.
- The surface is bounded by a curve.
- Bands may sometimes be seen on the smooth surface - 'beach marks'. They show the progress of the crack front from the point of origin.
- The surface is 90° to the load.
- Final fracture will usually take the form of gross yielding (as the maximum stress in the remaining ligament increase!).
- Fatigue crack need initiation + propagation periods.

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Fatigue Fracture

If a material is subjected to a static load, final rupture is preceded by very large strains.

If the same material is subjected to **cyclic loads**, failure may occur:

- At stress well below elastic limit.
- With little or no plastic deformation.

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Fatigue Fracture

Location: Any stress concentration area.

Steel Type: All steel types.

Susceptible Microstructure: All grain structures.

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Fatigue Fracture

- Fatigue cracks occur under cyclic stress conditions.
- Fracture normally occurs at a change in section, notch and weld defects ie stress concentration area.
- All materials are susceptible to fatigue cracking.
- Fatigue cracking starts at a specific point referred to as a initiation point.
- The fracture surface is smooth in appearance sometimes displaying beach markings.
- The final mode of failure may be brittle or ductile or a combination of both.

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Fatigue Fracture

Precautions against Fatigue Cracks

- Toe grinding, profile grinding.
- The elimination of poor profiles.
- The elimination of partial penetration welds and weld defects.
- Operating conditions under the materials endurance limits.
- The elimination of notch effects eg mechanical damage cap/root undercut.
- The selection of the correct material for the service conditions of the component.

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Fatigue Fracture

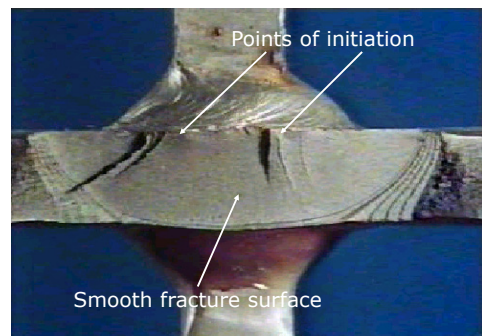


Fatigue cracking at the weld toe

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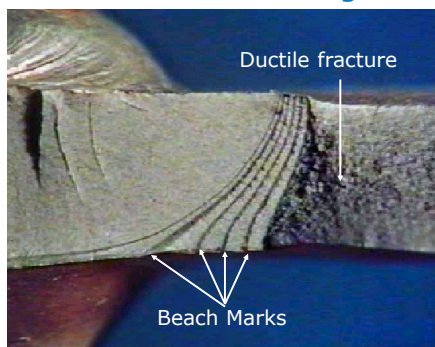
Fatigue Fracture



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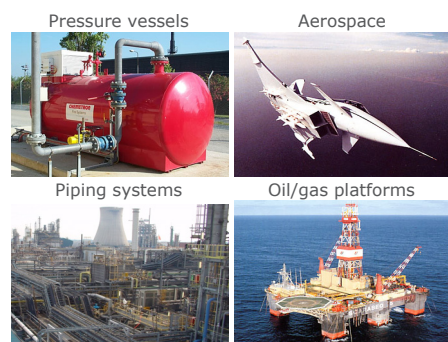
Fatigue Fracture



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Products Liable to Fatigue Failure



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Products Liable to Fatigue Failure

Overhead Cranes



Engineering plant

Lifting equipment



Rotating equipment



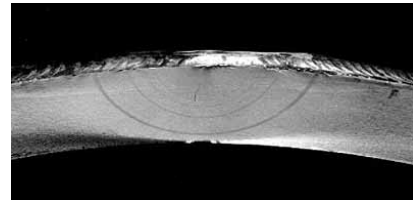
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Fatigue Fracture

Fatigue fracture occurs in structures subject to repeated application of tensile stress.

Crack growth is slow (in some cases, crack may grow into an area of low stress and stop without failure).



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Fractures

A large C-Mn structure is due for inspection after prolonged use.

It has been used in a variety of environments including temperatures below zero and at times subjected to intense cyclic loading.

There are a number of failed joints within the structure which you have to assess and report on.

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Question 1

A failure has occurred at the termination of a fillet weld. Part of the surface condition of the fractured surface shows variations in colour contrast between different parts. This can be described as:

- a. Beach marks
- b. Shear lips
- c. Reduction in area
- d. Crystallization marks

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Question 2

You discover a thick section failure, with a flat surface, over one metre long. You need to establish the initiation point of this failure. What feature on the failed surface could help you to find this?

- a. Crystalline zone
- b. Chevron marks
- c. Crescent marks
- d. Crack direction line

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Question 3

Cyclic loading can cause failure over time. What best describes this?

- a. Repeated loading of varying magnitude
- b. Loads above the UTS of the material
- c. Stress above the Rm point
- d. Impact loading at low temperatures

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Question 4

Brittle failure is consistent with which combinations?

- a. High temperature and static loading
- b. Low temperature and residual stress
- c. Temperatures that vary considerably and a load below R_e
- d. Temperatures above ambient and low loading

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Question 5

On the failed structure, some of the failures show distinct initiation points. Which of the following is more likely to be these points?

- a. Concave weld features
- b. Mitre like weld features
- c. Convex weld features
- d. Unequal leg length features

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Question 6

Brittle fracture occurs at:

- a. The speed of light
- b. Crack propagation is very slow
- c. The speed of sound
- d. Crack propagation is measured at 10mm per minute

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Question 7

Which failure combination is most common?

- a. Fatigue to brittle
- b. Ductile to Brittle
- c. Ductile to Fatigue
- d. Fatigue to Ductile

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Question 8

Which of the following materials does not suffer from fatigue failure?

- a. HSLA
- b. 316L stainless steel
- c. Q/T steels
- d. None of the options are correct

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Question 9

One of the failed joints on the structure, has a torn feature with shear lips at the point of failure. What is the most likely cause of this failure?

- a. Cyclic loading
- b. High residual stress
- c. Over loading
- d. Over loading in combination with low temperatures

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Question 10

Some of the failures show a smooth flat surface.
This is consistent with?

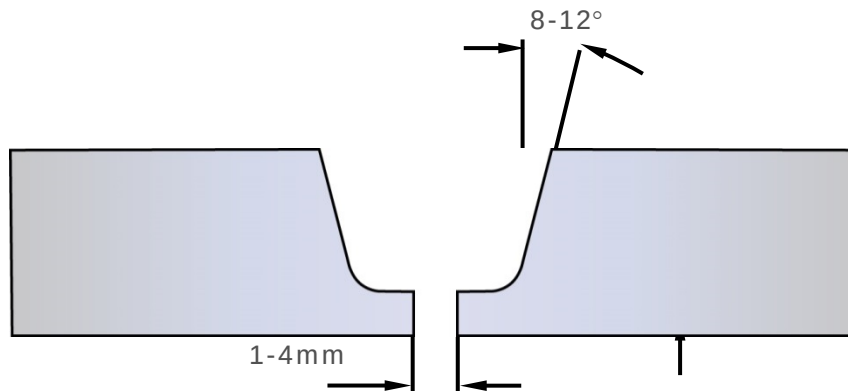
- a. Sudden failure
- b. Slow, progressive crack propagation
- c. Loading above the UTS value
- d. Ductile failure

Section 13

Welding Symbols

13 Welding Symbols

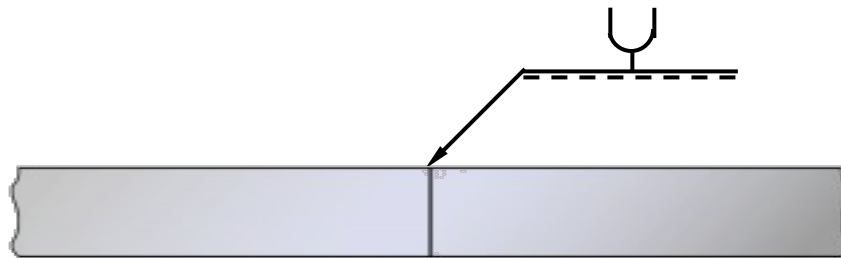
A weld joint can be represented on an engineering drawing by means of a detailed sketch showing every detail and dimension of the joint preparation - as shown below.



Single U preparation.

While this method of representation gives comprehensive information, it can be time-consuming and can also overburden the drawing.

An alternative method is to use a symbolic representation to specify the required information - as shown below for the same joint detail.



Symbolic representation has following advantages:

- Simple and quick to put on the drawing.
- Does not over-burden the drawing.
- No need for an additional view - all welding symbols can be put on the main assembly drawing.

Symbolic representation has following disadvantages:

- Can only be used for standard joints (eg BS EN ISO 9692).
- There is not a way of giving precise dimensions for joint details.
- Some training is necessary in order to interpret the symbols correctly.

13.1 Standards for symbolic representation of welded joints on drawings

There are two principal standards that are used for welding symbols:

European Standard

BS EN ISO 2553 – Welded, brazed and soldered joints – Symbolic representation on drawings.

American Standard

AWS A2.4 – Standard Symbols for Welding, Brazing, and Non-destructive Examination.

These standards are very similar in many respects, but there are also some major differences that need to be understood to avoid mis-interpretation.

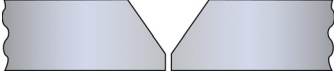
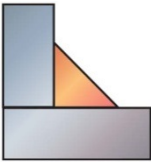
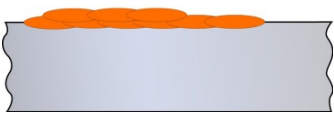
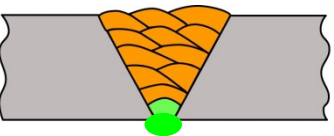
Details of the European Standard are given in the following sub-sections with only brief information about how the American Standard differs from the European Standard.

Elementary Welding Symbols

Various types of weld joint are represented by a symbol that is intended to help interpretation by being similar to the shape of the weld to be made.

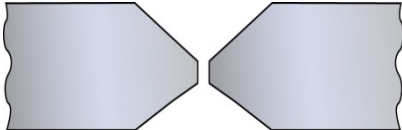
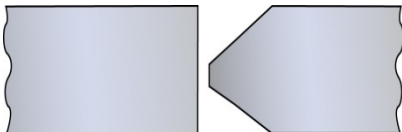
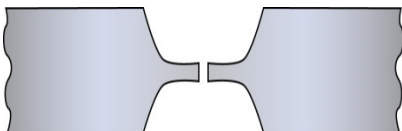
Examples of symbols used by BS EN ISO 2553 are shown on following pages.

13.2 Elementary welding symbols

Designation	Illustration of joint preparation	Symbol
Square butt weld		
Single V butt weld		∇
Single bevel butt weld		∇
Single V butt weld with broad root face		Y
Single bevel butt weld with broad root face		Y
Single U butt weld		U
Single J butt weld		J
Fillet weld		△
Surfacing (cladding)		3
Backing run (back or backing weld)		⌒
Backing bar		▬

13.3 Combination of elementary symbols

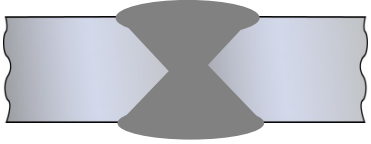
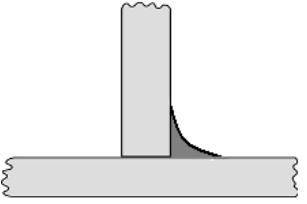
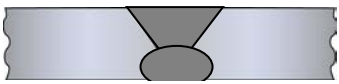
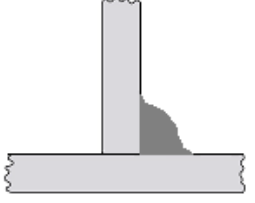
For symmetrical welds made from both sides, the applicable elementary symbols are combined – as shown below.

Designation	Illustration of joint preparation	Symbol
Double V butt weld (X weld)		
Double bevel butt weld (K weld)		
Double U butt weld		
Double J butt weld		

13.4 Supplementary symbols

Weld symbols may be complemented by a symbol to indicate the required shape of the weld.

Examples of supplementary symbols and how they are applied are given below.

Designation	Illustration of joint preparation	Symbol
Flat (flush) single V butt weld		
Convex double V butt weld		
Concave fillet weld		
Flat (flush) single V butt weld with flat (flush) backing run		
Single V butt weld with broad root face and backing run		
Fillet weld with both toes blended smoothly		

Note: If the weld symbol does not have a supplementary symbol then the shape of the weld surface does not need to be indicated precisely.

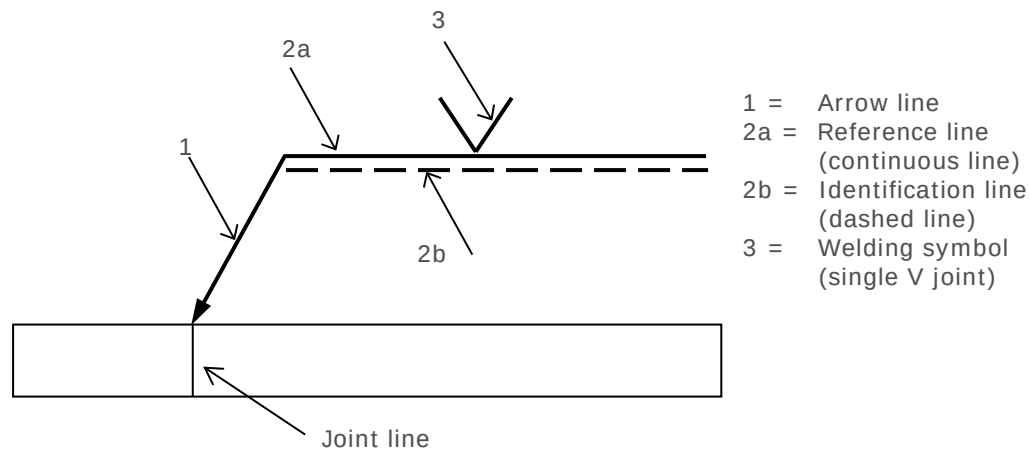
13.5 Position of symbols on drawings

In order to be able to provide comprehensive details for weld joints, it is necessary to distinguish the two sides of the weld joint.

The way this is done, according to BS EN ISO 2553, is by means of:

- An arrow line.
- A dual reference line consisting of a continuous line and a dashed line.

Below illustrates the method of representation.



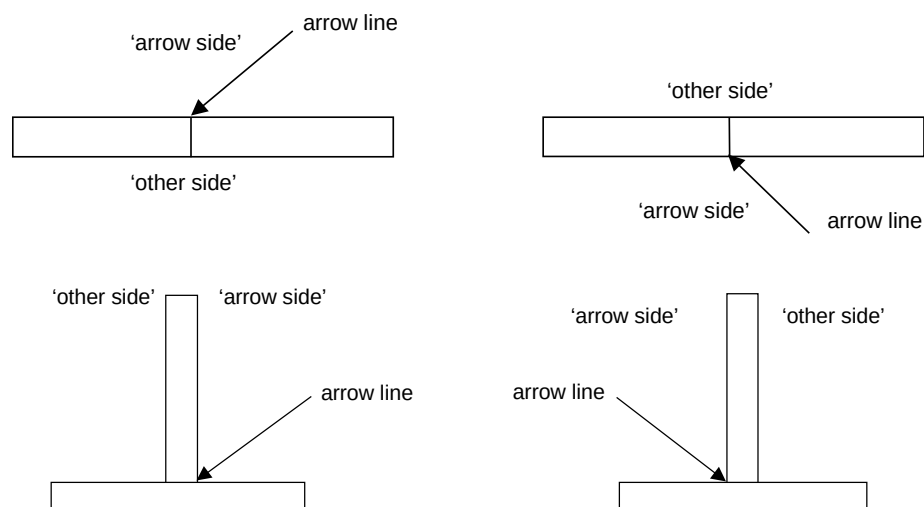
13.6 Relationship between the arrow line and the joint line

One end of the joint line is called the **arrow side** and the opposite end is called **other side**.

The arrow side is always the end of the joint line that the arrow line points to (and touches).

It can be at either end of the joint line and it is the draughtsman who decides which end to make the arrow side.

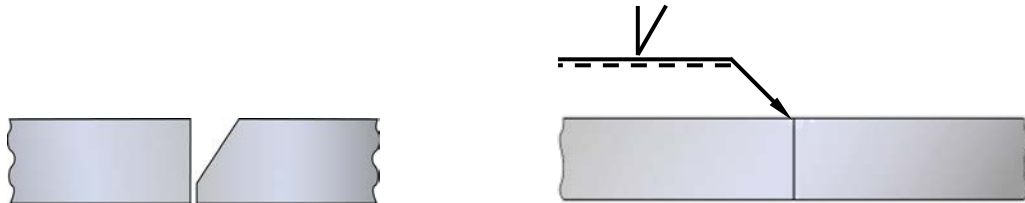
Below illustrates these principles.



There are some conventions about the arrow line:

- It must touch one end of the joint line.
- It joins one end of the continuous reference line.
- In case of a **non-symmetrical joint**, such as a single bevel joint, the arrow line must point towards the joint member that will have the weld preparation put on to it (as shown below).

An example of how a single-bevel butt joint should be represented is shown below.



13.7 Position of the reference line and position of the weld symbol

The reference line should, wherever possible, be drawn parallel to the bottom edge of the drawing (or perpendicular to it).

For a non-symmetrical weld it is essential that the arrow side and other side of the weld be distinguished.

The convention for doing this is:

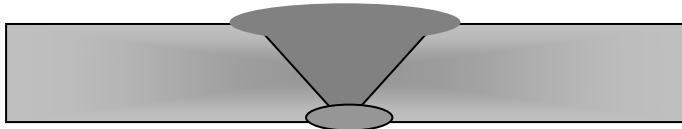
- Symbols for the weld details required on the arrow side must be placed on the continuous line.
- Symbols for the weld details on other side must be placed on the dashed line.

13.8 Positions of the continuous line and the dashed line

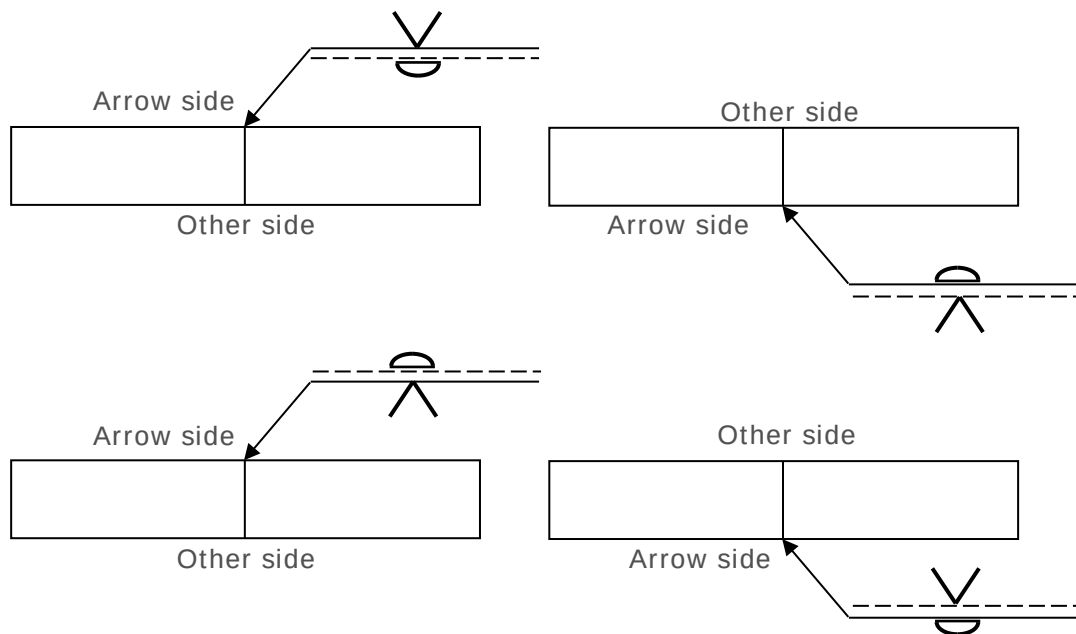
BS EN ISO 2553 allows the dashed line to be either above or below the continuous line – as shown below.



If the weld is a symmetrical weld then it is not necessary to distinguish between the two sides and BS EN ISO 2553 states that the dashed line should be omitted. Thus, a single V butt weld with a backing run can be shown by either of the four symbolic representations shown below.



Single V weld with a backing run



Note: This flexibility with the position of the continuous and dashed lines is an interim measure that BS EN ISO 2553 allows so that old drawings (to the obsolete BS 499 Part 2, for example) can be conveniently converted to show the EN method of representation.

13.9 Dimensioning of welds

General rules

Dimensions may need to be specified for some types of weld and BS EN ISO 2553 specifies a convention for this.

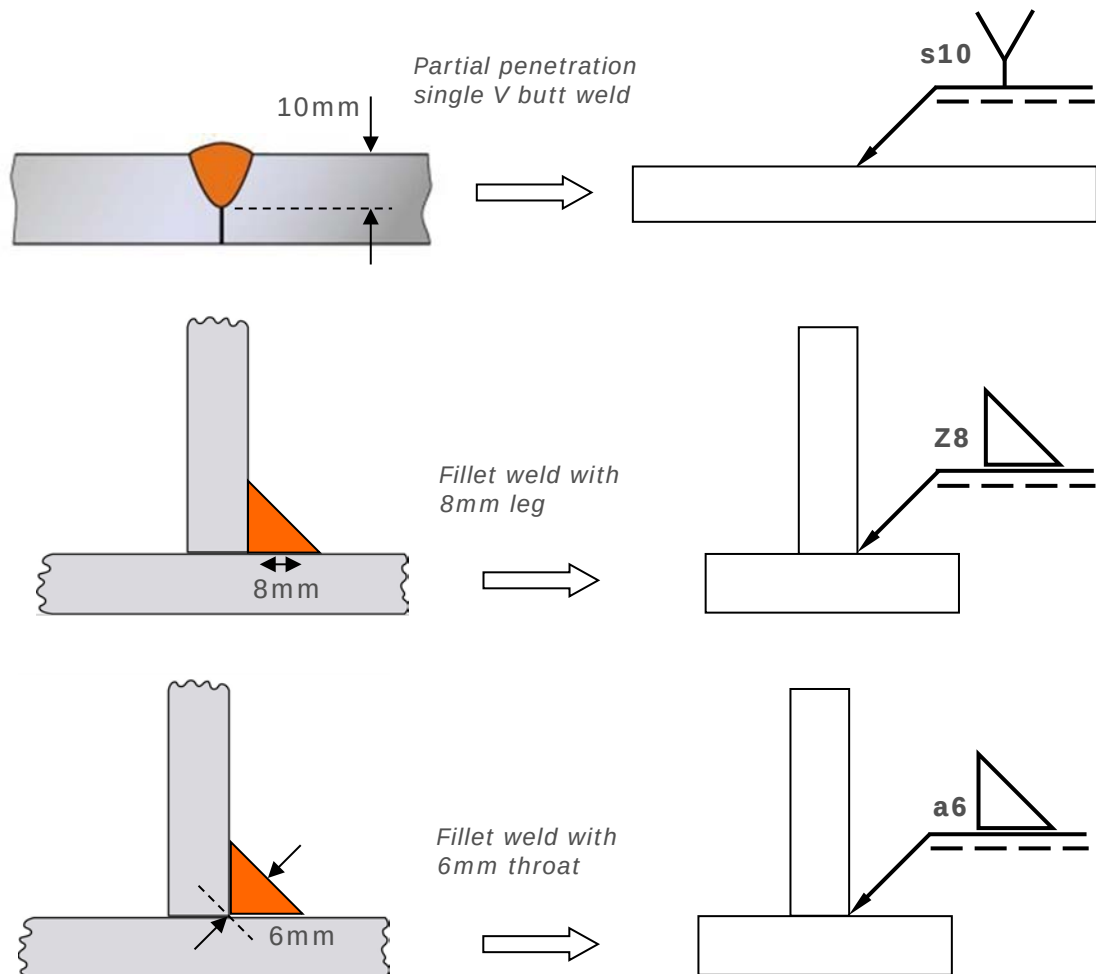
- Dimensions for the cross-section of the weld are written on the left-hand side of the symbol.
- Length dimensions for the weld are written on the right hand side of the symbol.
- In the absence of any indication to the contrary, all butt welds are full penetration welds.

13.9.1 Symbols for cross-section dimensions

The following letters are used to indicate dimensions:

- a Fillet weld throat thickness.
- Z Fillet weld leg length.
- s Penetration depth.
(Applicable to partial penetration butt welds and deep penetration fillets..)

Some examples of how these symbols are used are shown below.

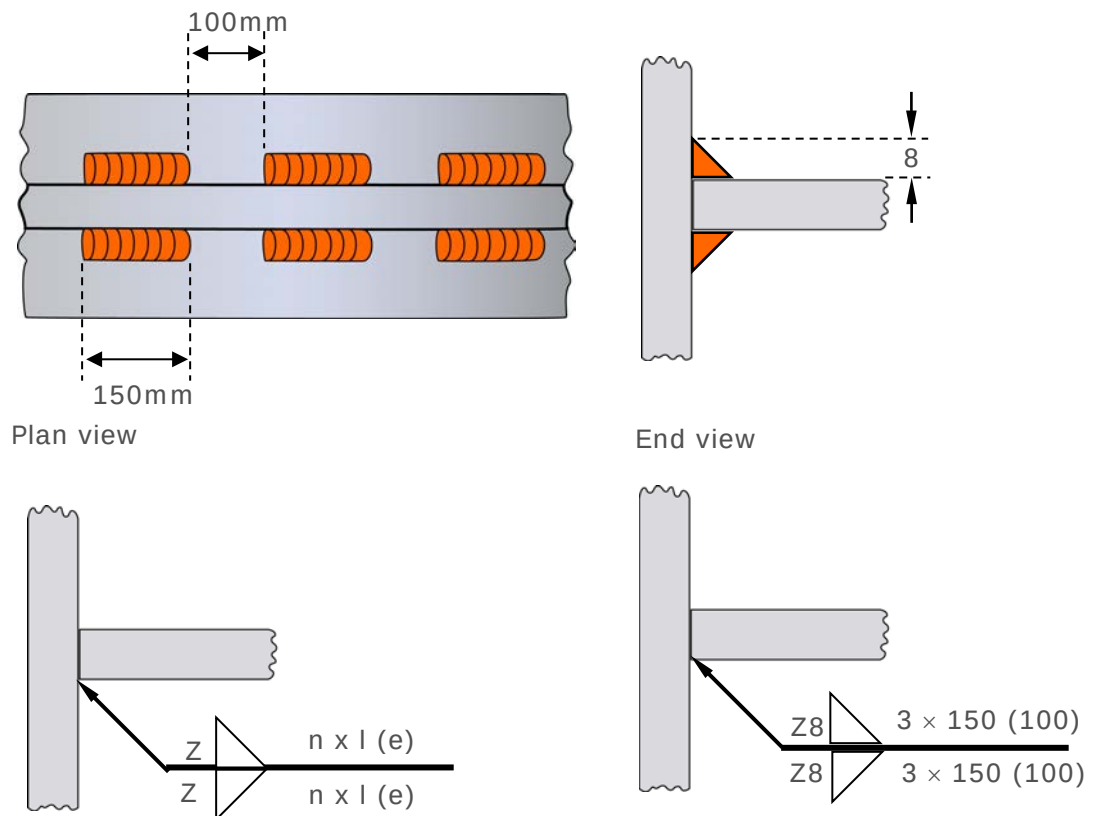


13.9.2 Symbols for length dimensions

To specify weld length dimensions and, for intermittent welds the number of individual weld lengths (weld elements), the following letters are used:

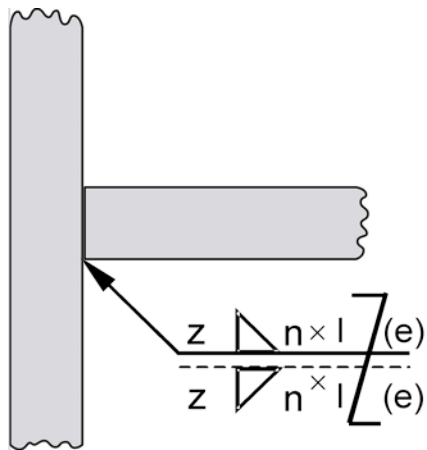
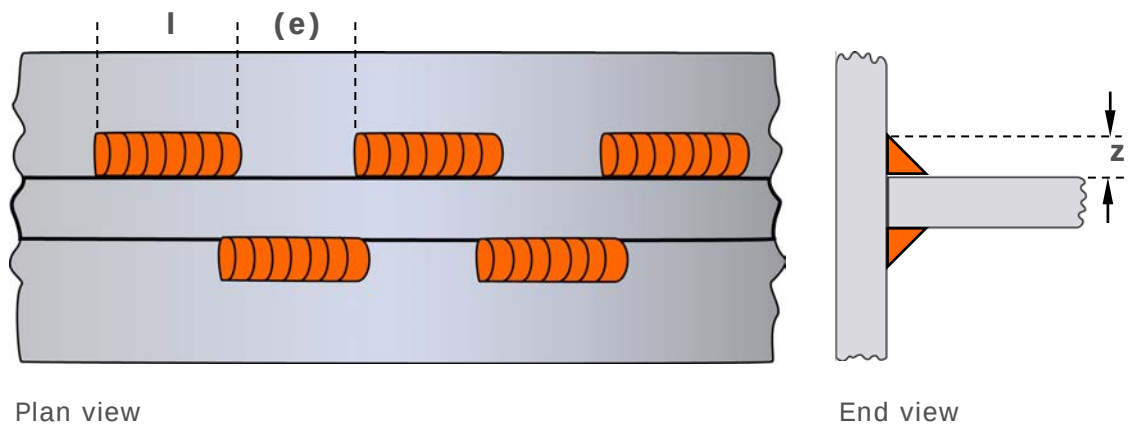
- l Length of weld.
- (e) Distance between adjacent weld elements.
- n Number of weld elements.

The use of these letters is illustrated for the intermittent double-sided fillet weld shown below.



Note: dashed line not required because it is a symmetrical weld.

If an intermittent double-sided fillet weld is to be staggered, the convention for indicating this is shown below.

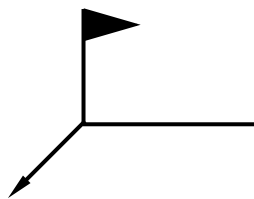


13.9.3 Complementary indications

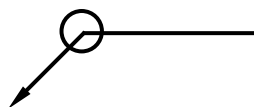
Complementary indications may be needed to specify other characteristics of welds.

Examples are:

- Field or site welds is indicated by a flag.

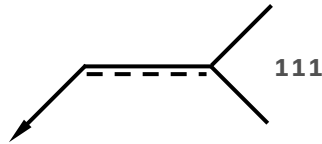


- A peripheral weld, to be made all around a part, is indicated by a circle.



13.10 Indication of the welding process

If required, the welding process is to be symbolised by a number written between the two branches of a fork at the end of the reference line – as shown below.



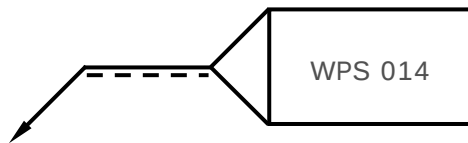
Some welding process designations

111 = MMA
121 = SAW
131 = MIG
135 = MAG
141 = TIG

13.11 Other Information in the tail of the reference line

In addition to specifying the welding process, other information can be added to an **open tail** (shown above) such as the NDT acceptance level the working position and the filler metal type and BS EN ISO 2553 defines the sequence that must be used for this information.

A closed tail can also be used into which reference to a specific instruction can be added – as shown below.



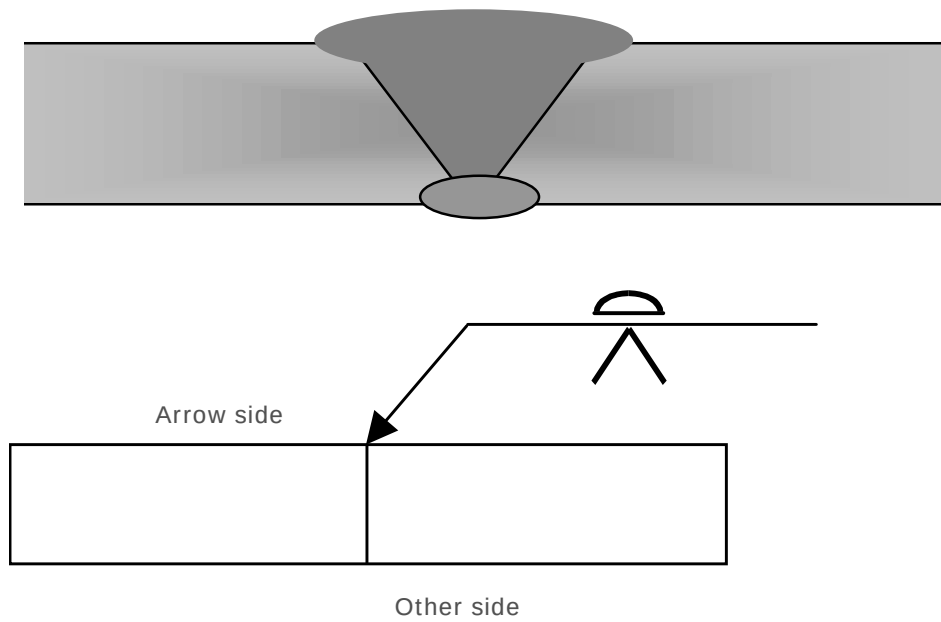
13.12 Weld symbols in accordance with AWS 2.4

Many of the symbols and conventions that are specified by BS EN ISO 2553 are the same as those used by AWS.

The major differences are:

- Only one reference line is used (a continuous line).
- Symbols for weld details on the **arrow side** go **underneath the reference line**.
- Symbols for weld details on the **other side** go **on top of the reference line**.

These differences are illustrated by the following example.



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Welding Symbols

Section 13

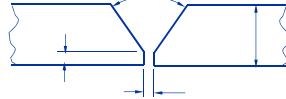
Materials Joining and Engineering Technologies
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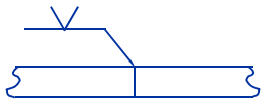
Weld Symbols on Drawings

Joints in drawings may be indicated

- By detailed sketches, showing every dimension.



- By symbolic representation.



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Weld Symbols on Drawings

A method of transferring information from the design office to the workshop is:



The above information does not tell us much about the wishes of the designer. We obviously need some sort of code which would be understood by everyone.

Most countries have their own standards for symbols. Some of them are AWS A2.4 & BS EN ISO 2553

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Weld Symbols on Drawings

Advantages of symbolic representation

- Simple and quick plotting on the drawing.
- Does not over-burden the drawing.
- No need for additional view.
- Gives all necessary indications regarding the specific joint to be obtained.

Disadvantages of symbolic representation

- Used only for usual joints.
- Requires training for properly understanding of symbols.

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Weld Symbols on Drawings

The symbolic representation includes

- An arrow line.
- A reference line.
- An elementary symbol.

The elementary symbol may be completed by

- A supplementary symbol.
- A means of showing dimensions.
- Some complementary indications.

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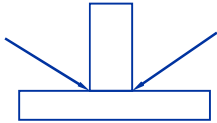
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Arrow Line

(BS EN ISO 2553 & AWS A2.4)

Convention of the arrow line

- Shall** touch the joint intersection.
- Shall** not be parallel to the drawing.
- Shall** point towards a single plate preparation (when only one plate has preparation).



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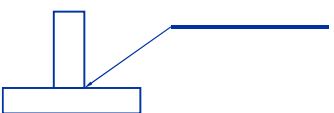
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Reference Line

(AWS A2.4)

Convention of the reference line

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



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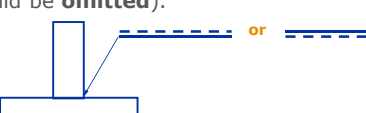
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Reference Line

(BS EN ISO 2553)

Convention of the reference line

- **Shall** touch the arrow line.
- **Shall** be parallel to the bottom of the drawing.
- **There shall** be a further broken identification line above or beneath the reference line (Not necessary where the weld is symmetrical and should be **omitted**).



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Elementary Welding Symbols

(BS EN ISO 2553 & AWS A2.4)

Convention of the elementary symbols

- Various categories of joints are characterised by an elementary symbol.
- The vertical line in the symbols for a fillet weld, single/double bevel butts and a J-butt welds must always be on the left side.

Weld type	Sketch	Symbol
Square edge butt weld		
Single-v butt weld		

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Elementary Welding Symbols

Weld type	Sketch	Symbol
Single-V butt weld with broad root face		
Single bevel butt weld		
Single bevel butt weld with broad root face		
Backing run		

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Elementary Welding Symbols

Weld type	Sketch	Symbol
Single-U butt weld		
Single-J butt weld		
Surfacing		
Fillet weld		

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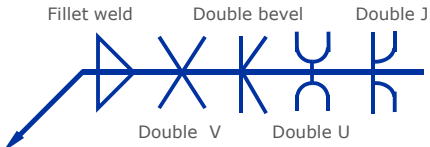
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Double Side Weld Symbols

(BS EN ISO 2553 & AWS A2.4)

Convention of the double side weld symbols

Representation of welds done from **both sides** of the joint intersection, touched by the arrow head.



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Dimensions

Convention of dimensions

In most standards the cross sectional dimensions are given to the left side of the symbol, and all linear dimensions are given on the right side.

BS EN ISO 2553

a = Design throat thickness.
s = Depth of Penetration, Throat thickness.
z = Leg length (min material thickness).

AWS A2.4

- In a fillet weld, the size of the weld is the leg length.
- In a butt weld, the size of the weld is based on the depth of the joint preparation.

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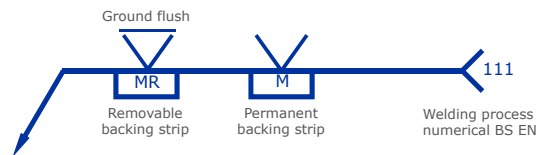


Supplementary Symbols

(BS EN ISO 2553 & AWS A2.4)

Convention of supplementary symbols

Supplementary information such as welding process, weld profile, NDT and any special instructions



Further supplementary information, such as WPS number, or NDT may be placed in the fish tail

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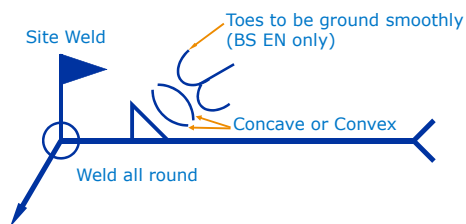


Supplementary Symbols

(BS EN ISO 2553 & AWS A2.4)

Convention of supplementary symbols

Supplementary information such as welding process, weld profile, NDT and any special instructions



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Welding Symbols

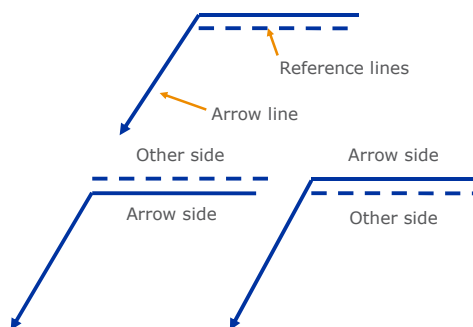
BS EN ISO 2553



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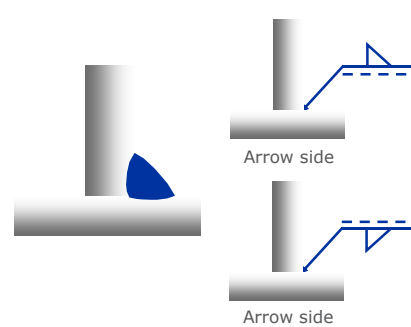
BS EN ISO 2553



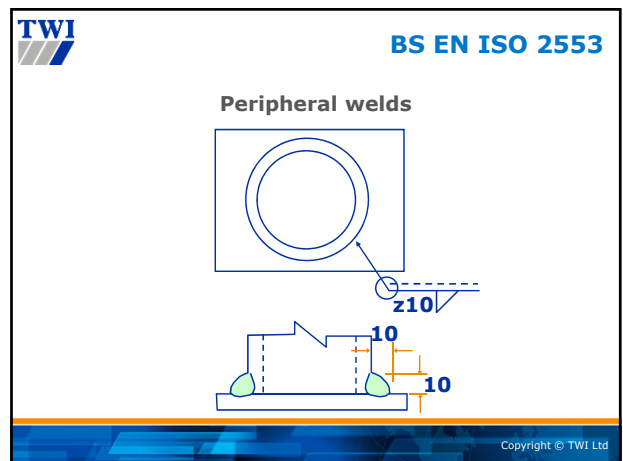
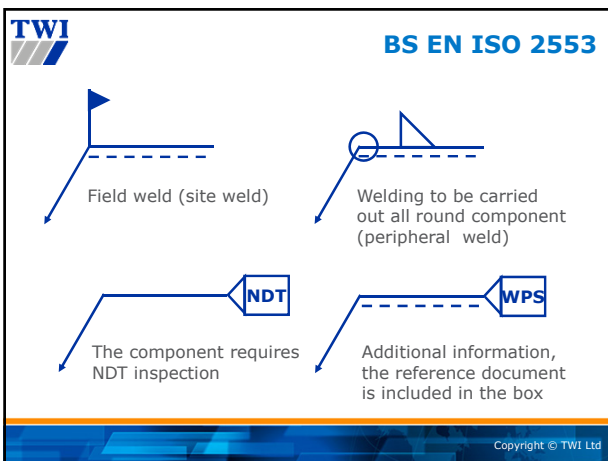
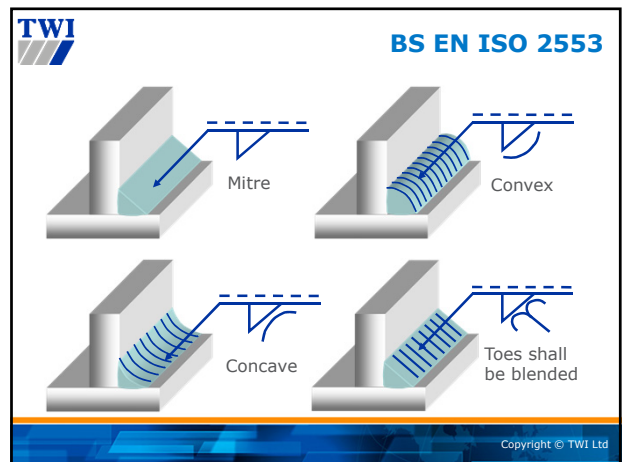
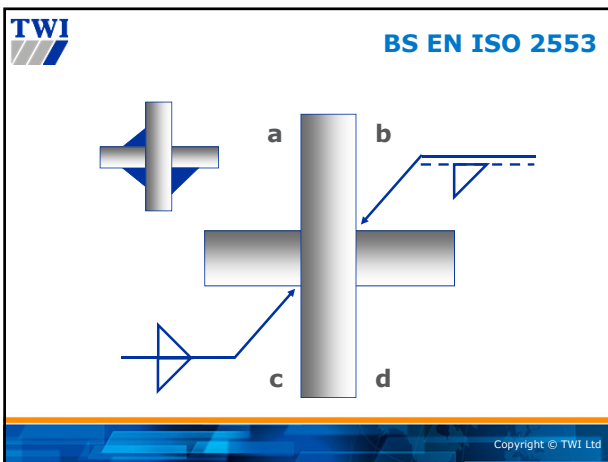
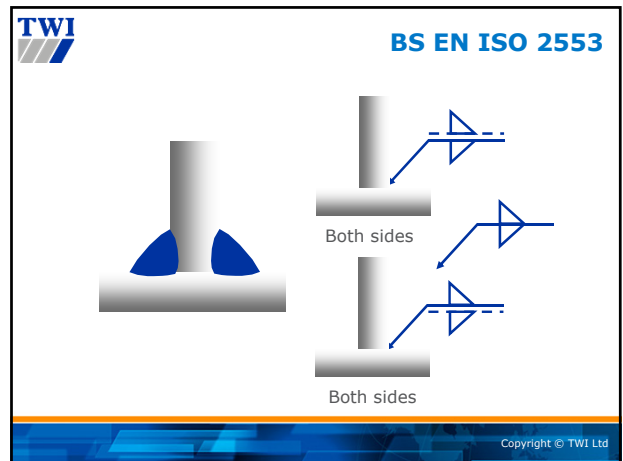
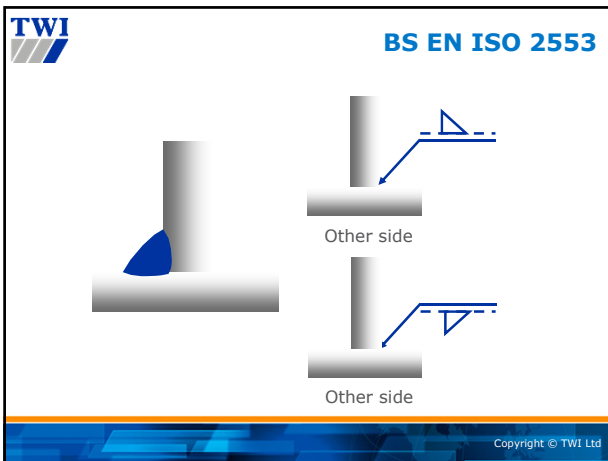
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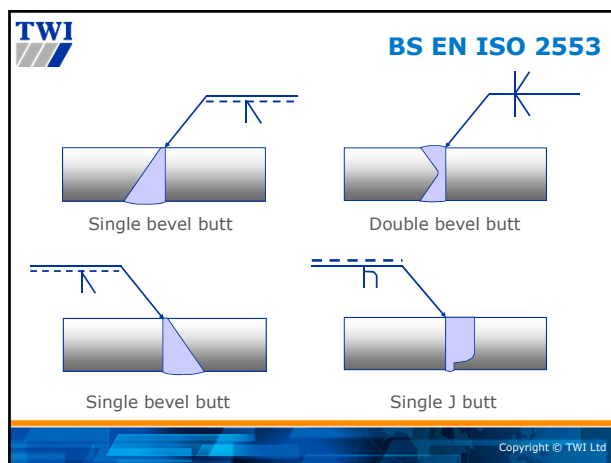
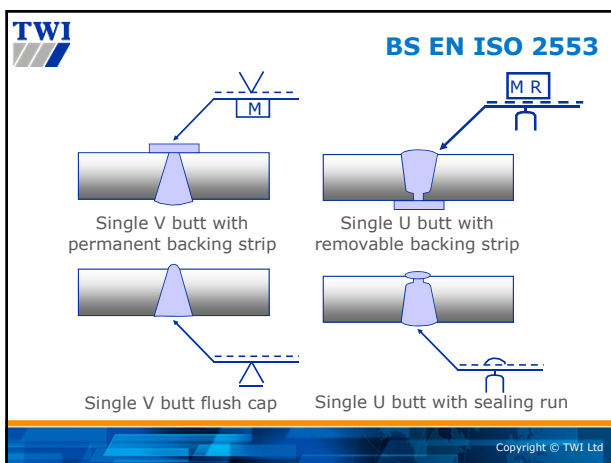
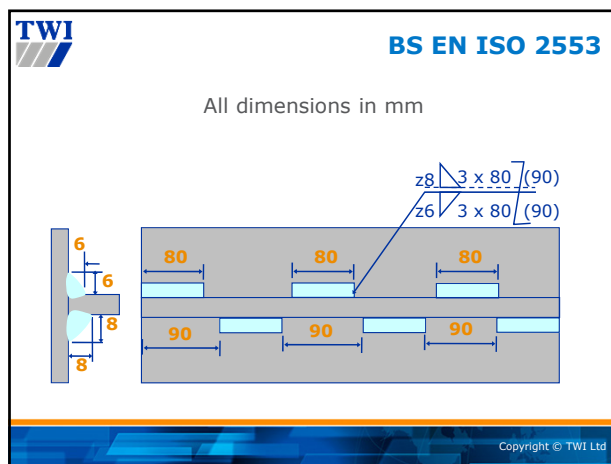
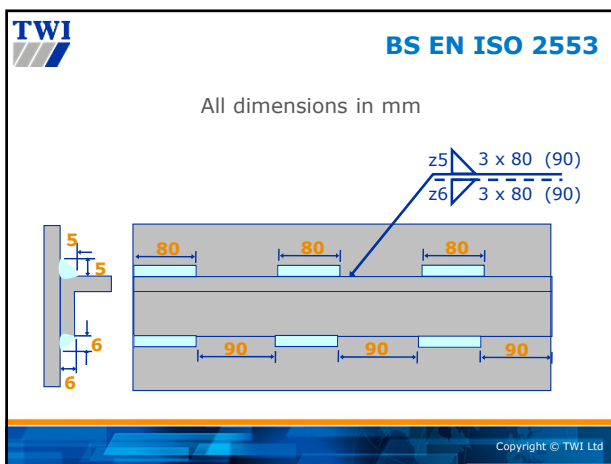
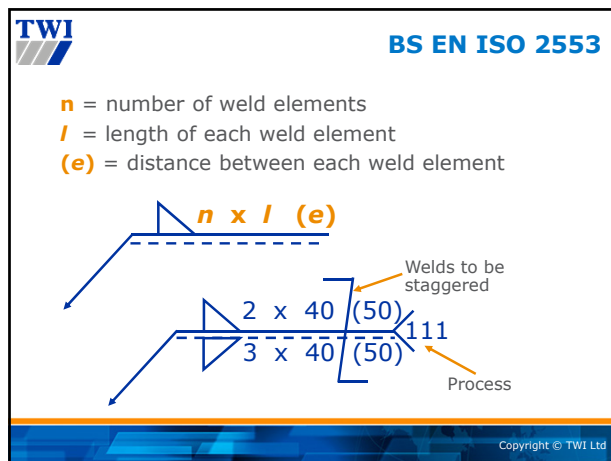
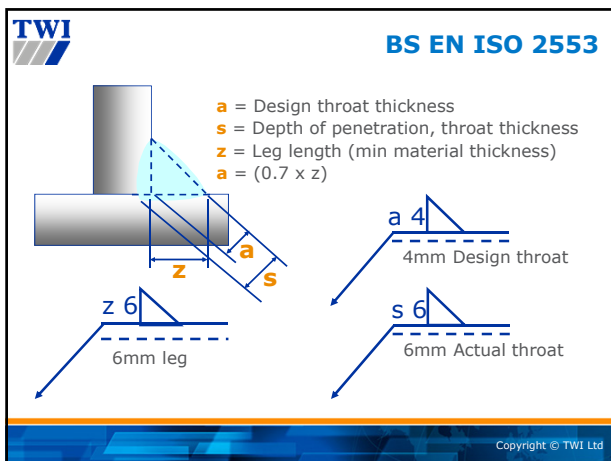


BS EN ISO 2553



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**BS EN ISO 2553
Rules - Example**

All leg lengths **shall** be preceded by z and throat by a or s (in case of deep penetration welds)

Diagram illustrating a T-joint weld. The weld is shown in cross-section and is labeled with dimensions: $z\ 10$, $3 \times 50\ (50)$, 50 , and 10 .

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Welding Symbols

AWS A2.4

Diagram illustrating the AWS logo, which is a diamond shape containing the letters "AWS".

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AWS Welding Symbols

Diagram illustrating a V-groove weld. The weld is shown in cross-section and is labeled with dimensions: $1\ (1-1/8)$, $1/8$, 60° . The labels point to the following features: Depth of bevel, Root opening, Effective throat, and Groove angle.

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AWS Welding Symbols

Diagram illustrating a V-groove weld. The weld is shown in cross-section and is labeled with dimensions: $1\ (1-1/8)$, $1/8$, 60° . The label "Welding process" points to the weld, and the label "GSFCW" points to the weld. The labels "GMAW", "GTAW", and "SAW" are also present.

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AWS Welding Symbols

Diagram illustrating a staggered weld joint. The weld is shown in cross-section and is labeled with dimensions: $3 - 10$, $3 - 10$, 3 , and 10 . The label "Welds to be staggered" points to the weld, and the label "SMAW" points to the weld. The label "Process" points to the weld.

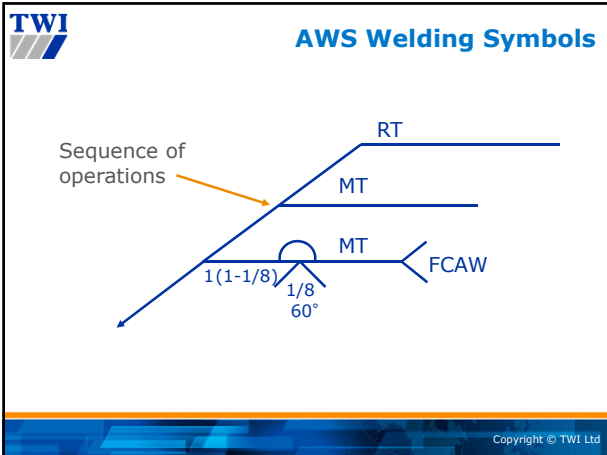
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AWS Welding Symbols

Diagram illustrating a sequence of operations weld. The weld is shown in cross-section and is labeled with dimensions: $1\ (1-1/8)$, $1/8$, 60° . The label "Sequence of operations" points to the weld, and the labels "3rd Operation", "2nd Operation", and "1st Operation" point to the weld. The label "FCAW" points to the weld.

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AWS A 2.4 Rules

Welds **on arrow side** of joint go **underneath** the reference line while welds **the other side** of the joint, go **on top** of the reference line.

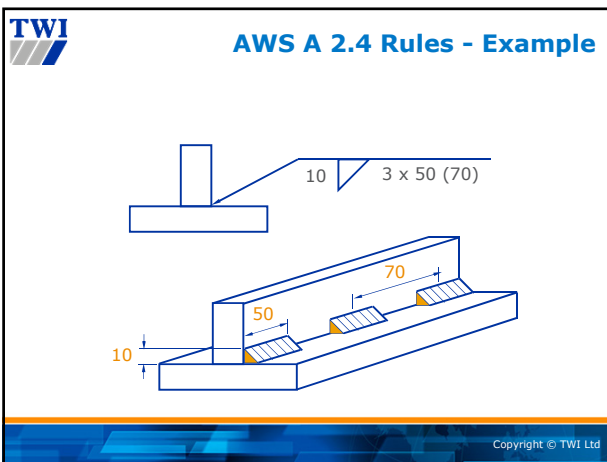
Symbols with a **vertical line** component must be drawn with the vertical line to the **left side** of the symbol.

All **CSA** dimensions are shown to the **left** of the symbol.

All **linear** dimensions are shown on the **right** of the symbol ie number of welds, length of welds, length of any spaces.

Included angle and root opening are shown on **top** of the symbol.

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Any Questions

?

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10 Questions relating to Welding Symbols – refer to Vessel Drawing 1 in Appendix 3

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Question 1

Based on the information given, what would be the appropriate weld symbol to BS EN ISO 2553 for the joint numbered 1, if the excess weld metal was removed to allow ultrasonic testing from the outside of the vessel? The joint has been welded using the FCAW process.

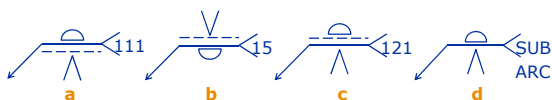
a b c d

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Question 2

Based on the information given, what would be the appropriate weld symbol to BS EN ISO 2553 for the joint numbered 2, if it was welded from the outside of the vessel by the SAW process with a sealing run on the inside of the vessel?

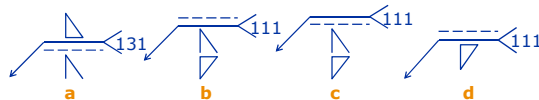


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Question 3

At position 3, what would be the appropriate weld symbol to BS EN ISO 2553, if a set on nozzle type configuration, welded from the outside of the vessel using the MMA welding process?

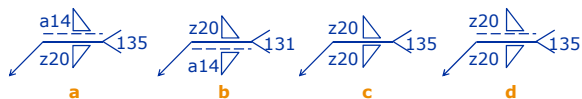


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Question 4

At position 3, what would be the appropriate weld symbol to BS EN ISO 2553, if a set through joint configuration was used and a 14mm design throat was required on the inside, and a 20mm leg length fillet on the outside of the vessel, using the MAG welding process?

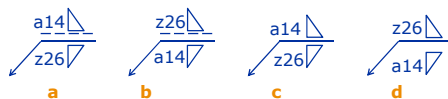


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Question 5

At position 4 on the vessel, what would be the appropriate symbol to BS EN ISO 2553, if a fillet weld was required with a 26mm leg length fillet on the outside of the flange and a 14mm design throat on the inside on the flange?

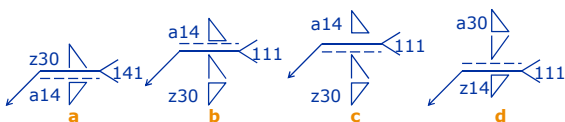


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Question 6

At position 3 on the vessel, what would be the appropriate weld symbol to BS EN ISO 2553, if a compound weld was required on the outside of the vessel with a 30mm leg length and a 14mm design throat weld on the inside of the vessel using the MMA process?

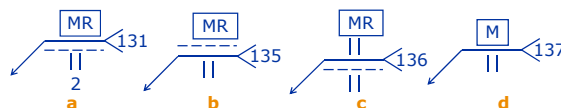


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Question 7

At position 1, the material thickness has been changed to 5mm. What would be the appropriate welding symbol to BS EN ISO 2553, if a single sided weld from the outside of the vessel was used with removable backing using the MAG process?



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Question 8

When using BS EN ISO 2553 , the term symmetrical means?

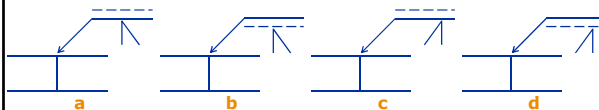
- a. The same, arrow and other side
- b. Different arrow and other side
- c. Only refers to the arrow side
- d. Only refers to the other side

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Question 9

At position 2 on the vessel, if a single sided bevel joint was required on the dished end when welding from the outside, in accordance with BS EN ISO 2553 which would be the correct symbol?



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Question 10

The letter s preceding a symbol dimension to BS EN ISO 2553 means?

- a. Weld requires flushing
- b. Toes require blending
- c. Depth of penetration
- d. Standard shape

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Section 14

NDT

14 NDT

Radiographic, ultrasonic, dye-penetrant and magnetic particle methods are briefly described below. The relative advantages and limitations of the methods are discussed in terms of their applicability to the examination of welds.

14.1 Radiographic methods

In all cases radiographic methods as applied to welds involve passing a beam of penetrating radiation through the test object. The transmitted radiation is collected by some form of sensor, which is capable of measuring the relative intensities of penetrating radiations impinging upon it.

In most cases this sensor will be a radiographic film; however the use of various electronic devices is on the increase. These devices facilitate so-called real time radiography and examples may be seen in the security check area at most airports.

Digital technology has enabled the storing of radiographs using computers. The present discussion is confined to film radiography since this is still by far the most common method applied to welds.

14.1.1 Sources of penetrating radiation

Penetrating radiations may be generated from high-energy electron beams, in which case they are termed X rays, or from nuclear disintegrations (atomic fission), in which case they are termed γ -rays. Other forms of penetrating radiation exist but they are of limited interest in weld radiography.

14.1.2 X rays

X rays used in the industrial radiography of welds generally have photon energies in the range 30keV up to 20MeV. Up to 400keV they are generated by conventional X ray tubes which dependant upon output may be suitable for portable or fixed installations.

Portability falls off rapidly with increasing kilovoltage and radiation output. Above 400keV X rays are produced using devices such as betatrons and linear accelerators. These devices are not generally suitable for use outside of fixed installations. All sources of X rays produce a continuous spectrum of radiation, reflecting the spread of kinetic energies of electrons within the electron beam.

Low energy radiations are more easily absorbed and the presence of low energy radiations, within the X ray beam, gives rise to better radiographic contrast and therefore better radiographic sensitivity than is in the case with γ -rays which are discussed below.

Conventional X ray units are capable of performing high quality radiography on steel of up to 60mm thickness, betatrons and linear accelerators are capable of penetrating in excess of 300mm of steel.

14.1.3 γ -rays

The early sources of γ -rays used in industrial radiography were in general composed of naturally occurring radium. The activity of these sources was not very high, therefore they were physically rather large by modern standards even for quite modest outputs of radiation and the radiographs produced by them were not of a particularly high standard.

Radium sources were also extremely hazardous to the user due to the production of radioactive radon gas as a product of the fission reaction. Since the advent of the nuclear age it has been possible to artificially produce isotopes of much higher specific activity than those occurring naturally and which do not produce hazardous fission products. Unlike the X-ray sources γ -sources do not produce a continuous distribution of quantum energies. γ -sources produce a number of specific quantum energies which are unique for any particular isotope.

Four isotopes are in common use for the radiography of welds; they are in ascending order of radiation energy: thulium 90, ytterbium 169, iridium 192 and cobalt 60. In terms of steel thulium 90 is useful up to a thickness of 7mm or so, its energy is similar to that of 90keV X rays and due to its high specific activity useful sources can be produced with physical dimensions of less than 0.5mm.

Ytterbium 169 has only fairly recently become available as an isotope for industrial use, its energy is similar to that of 120keV X rays and it is useful for the radiography of steel up to approximately 12mm thickness.

Iridium 192 is probably the most commonly encountered isotopic source of radiation used in the radiographic examination of welds, it has a relatively high specific activity and high output sources with physical dimensions of 2-3mm are in common usage, its energy is approximately equivalent to that of 500 keV X rays and it is useful for the radiography of steel in the thickness range 10-75mm.

Cobalt 60 has an energy approximating to that of 1.2MeV X rays, due to this relatively high energy suitable source containers are large and rather heavy. Cobalt 60 sources are for this reason not fully portable. They are useful for the radiography of steel in the thickness range 40-150mm.

The major advantages of using isotopic sources over X rays are:

- a** The increased portability.
- b** The lack of the need for a power source.
- c** Lower initial equipment costs.

Against this the quality of radiographs produced by γ -ray techniques is inferior to that produced by X ray techniques, the hazards to personnel may be increased (if the equipment is not properly maintained, or if the operating personnel have insufficient training) and due to their limited useful lifespan new isotopes have to be purchased on a regular basis (so that the operating costs of a γ -ray source may exceed those of an X ray source).

14.1.4 Radiography of welds

Radiographic techniques depend upon detecting differences in absorption of the beam ie: changes in the effective thickness of the test object, in order to reveal defective areas.

Volumetric weld defects such as slag inclusions (except in some special cases where the slag absorbs radiation to a greater extent than does the weld metal) and various forms of gas porosity are easily detected by radiographic techniques due to the large negative absorption difference between the parent metal and the slag or gas.

Planar defects such as cracks or lack of side wall or inter-run fusion are much less likely to be detected by radiography since such defects may cause little or no change in the penetrated thickness. Where defects of this type are likely to occur other NDE techniques such as ultrasonic testing are preferable to radiography. This lack of sensitivity to planar defects makes radiography an unsuitable technique where a fitness-for-purpose approach is taken when assessing the acceptability of a weld.

However, film radiography produces a permanent record of the weld condition, which can be archived for future reference; it also provides an excellent means of assessing the welder's performance and for these reasons it is often still the preferred method for new construction.

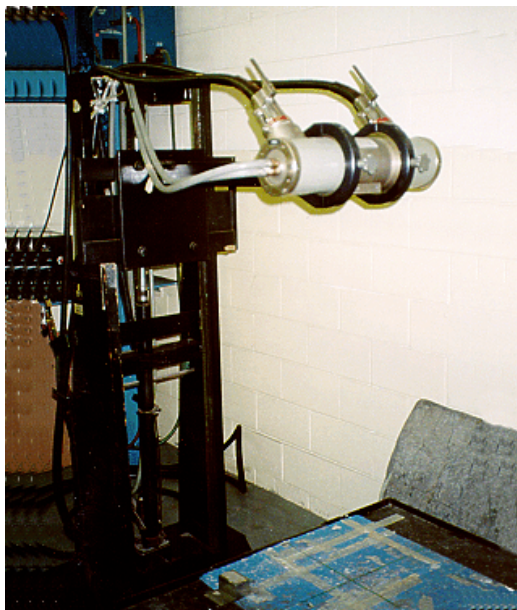


Figure 14.1 X ray equipment.



Figure 14.2 Gamma-ray equipment.



Figure 14.3 X ray of a welded seam showing porosity.

14.1.5 Radiographic testing

Advantages	Limitations
■ Permanent record ■ Good for sizing non planar defects/flaws ■ Can be used on all materials ■ Direct image of defects/flaws ■ Real-time imaging ■ Can be position inside pipe (productivity) ■ Very good thickness penetration available ■ No power required with gamma	■ Health hazard. Safety (important) ■ Classified workers, medicals required ■ Sensitive to defect orientation ■ Not good for planar defect detection ■ Limited ability to detect fine cracks ■ Access to both sides required ■ Skilled interpretation required ■ Relatively slow ■ High capital outlay and running costs ■ Isotopes have a half life (cost)

14.1.6 Ultrasonic methods

The velocity of ultrasound in any given material is a constant for that material and ultrasonic beams travel in straight lines in homogeneous materials. When ultrasonic waves pass from a given material with a given sound velocity to a second material with different velocity refraction and reflection of the sound beam will occur at the boundary between the two materials.

The same laws of physics apply equally to ultrasonic waves as they do to light waves. Because ultrasonic waves are refracted at a boundary between two materials having different acoustic properties, probes may be constructed which can beam sound into a material at (within certain limits) any given angle.

Because sound is reflected at a boundary between two materials having different acoustic properties ultrasound is a useful tool for the detection of weld defects. Because the velocity is a constant for any given material and because sound travels in a straight line (with the right equipment) ultrasound can also be utilised to give accurate positional information about a given reflector.

Careful observation of the echo pattern of a given reflector and its behaviour as the ultrasonic probe is moved together with the positional information obtained above and knowledge of the component history enables the experienced ultrasonic operator to classify the reflector as say slag lack of fusion or a crack.

14.1.7 Equipment for ultrasonic testing

Equipment for manual ultrasonic testing consists of:

a A flaw detector comprising:

- Pulse generator.
- Adjustable time base generator with an adjustable delay control.
- Cathode ray tube with fully rectified display.
- Calibrated amplifier with a graduated gain control or attenuator).

b An ultrasonic probe comprising:

- Piezo-electric crystal element capable of converting electrical vibrations to mechanical vibrations and vice-versa.
- Probe shoe, normally a Perspex block to which the crystal is firmly attached using a suitable adhesive.
- Electrical and/or mechanical crystal damping facilities to prevent excessive ringing.

Such equipment is lightweight and extremely portable. Automated or semi-automated systems for ultrasonic testing utilise the same basic equipment although in general this will be multi-channel equipment, it is bulkier and less portable.

Probes for automated systems are set in arrays and some form of manipulator is necessary in order to feed positional information about the probes to the computer. Automated systems generate very large amounts of data and make large demands upon the RAM of the computer. Recent advances in automated UT have led to a reduced amount of data being recorded for a given length of weld.

Simplified probe arrays have greatly reduced the complexity of setting up the automated system to carry out a particular task. Automated UT systems now provide a serious alternative to radiography on such constructions as pipelines where a large number of similar inspections allow the unit cost of system development to be reduced to a competitive level.



Figure 14.4 Ultrasonic equipment.

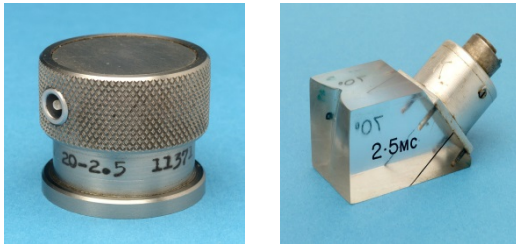


Figure 14.5 Compression and shear wave probes.

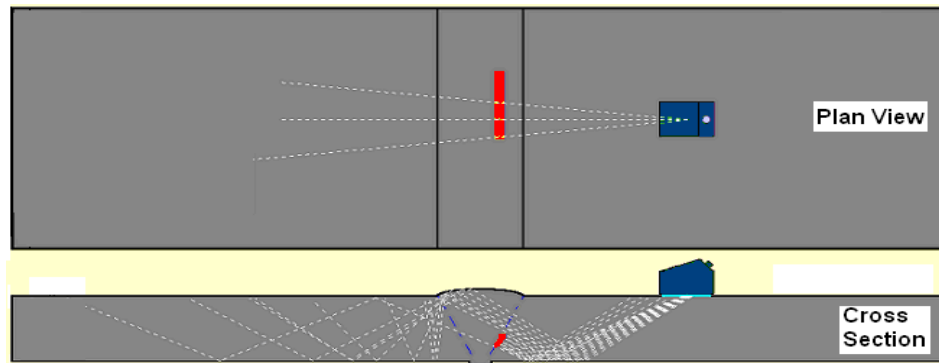


Figure 14.6 Scanning technique with a shear wave probe.

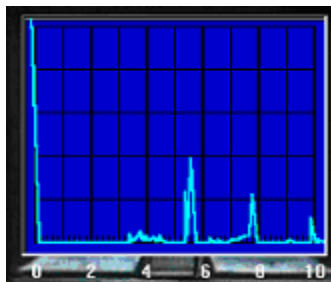


Figure 14.7 Typical screen display when using a shear wave probe.

14.1.8 Ultrasonic testing

Advantages	Limitations
■ Portable (no mains power) battery ■ Direct location of defect (3 dimensional) ■ Good for complex geometry ■ Safe operation (can be carried out next to someone) ■ Instant results ■ High penetrating capability ■ Can be done from one side only ■ Good for finding planar defects	■ No permanent record ■ Only ferritic materials (mainly) ■ High level of operator skill required ■ Calibration of equipment required ■ Special calibration blocks required ■ No good for pin pointing porosity ■ Critical of surface conditions (clean smooth) ■ Will not detect surface defects ■ Material thickness >8mm due to dead zone

14.2 Magnetic particle testing

Surface breaking or very near surface discontinuities in ferromagnetic materials give rise to leakage fields when high levels of magnetic flux are applied. These leakage fields will attract magnetic particles (finely divided magnetite) to themselves and this process leads to the formation of an indication.

The magnetic particles may be visibly or fluorescently pigmented in order to provide contrast with the substrate or conversely the substrate may be lightly coated with a white background paint in order to contrast with the particles. Fluorescent magnetic particles provide the greatest sensitivity. The particles will normally be in a liquid suspension and this will normally be applied by spraying.

In certain cases dry particles may be applied by a gentle jet of air. The technique is applicable only to ferromagnetic materials, which are at a temperature below the curie point (about 650°C). The leakage field will be greatest for linear discontinuities lying at right angles to the magnetic field. This means that for a comprehensive test the magnetic field must normally be applied in two directions, which are mutually perpendicular. The test is economical to carry out both in terms of equipment costs and rapidity of inspection. The level of operator training required is relatively low.



Figure 14.8 Magnetic particle inspection using a yoke.



Figure 14.9 Crack found using magnetic particle inspection.

14.2.1 Magnetic particle testing

Advantages	Limitations
■ Inexpensive equipment ■ Direct location of defect ■ Not critical of surface conditions ■ Could be applied without power ■ Low skill level ■ Sub defects surface 1-2mm ■ Quick instant results ■ Hot testing (using dry powder) ■ Can be used in the dark (UV light)	■ Only magnetic materials ■ May need to demagnetise components ■ Access may be a problem for the yoke ■ Need power if using a yoke ■ No permanent record ■ Calibration of equipment ■ Testing in two directions required ■ Need good lighting 500 Lux minimum

14.3 Dye penetrant testing

Any liquid that has good wetting properties will act as a penetrant. Penetrants are attracted into surface breaking discontinuities by capillary forces. Penetrant, which has entered a tight discontinuity, will remain even when the excess penetrant is removed.

Application of a suitable developer will encourage the penetrant within such discontinuities to bleed out. If there is a suitable contrast between the penetrant and the developer an indication visible to the eye will be formed. This contrast may be provided by either visible or fluorescent dyes. Use of fluorescent dyes considerably increases the sensitivity of the technique.

The technique is not applicable at extremes of temperature. At low temperatures (below 5°C) the penetrant vehicle, normally oil will become excessively viscous and this will cause an increase in the penetration time with a consequent decrease in sensitivity. At high temperatures (above 60°C) the penetrant will dry out and the technique will not work.

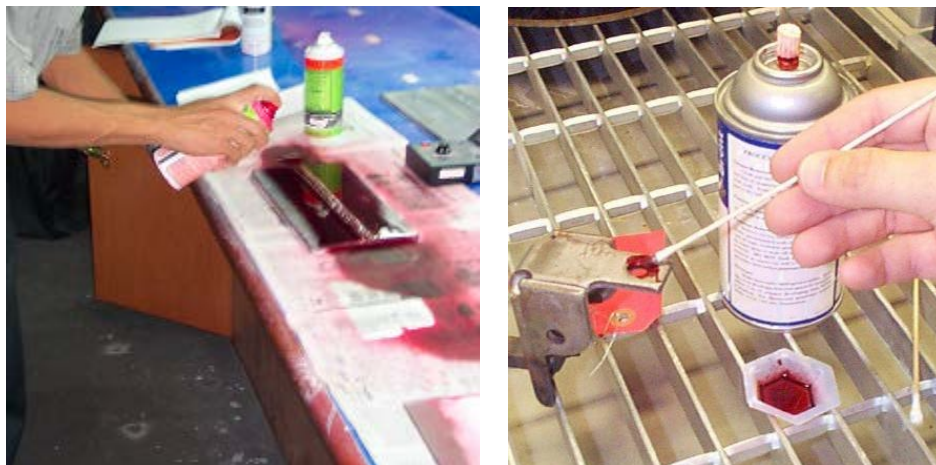


Figure 14.10 Methods of applying the red dye during dye-penetrant inspection.

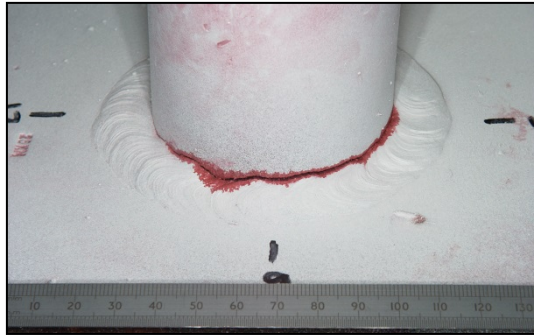


Figure 14.11 Crack found using dye-penetrant inspection.

14.3.1 Dye penetrant

Advantages	Limitations
■ All materials (non-porous) ■ Portable ■ Applicable to small parts with complex geometry ■ Simple ■ Inexpensive ■ Sensitivity ■ Relatively low skill level (easy to interpret)	■ Will only detect defects open to the surface ■ Requires careful surface preparation ■ Not applicable to porous surfaces ■ Temperature dependant ■ Cannot retest indefinitely ■ Potentially hazardous chemicals ■ No permanent record ■ Time lapse between application and results ■ Messy

14.4 Surface crack detection (magnetic particle / dye penetrant): general

When considering the relative value of NDE techniques, it should not be forgotten that most catastrophic failures initiate from the surface of a component, therefore the value of the magnetic particle and dye Penetrant techniques should not be underestimated.

Ultrasonic inspection may not detect near surface defects easily since the indications may be masked by echoes arising from the component geometry and should therefore be supplemented by an appropriate surface crack detection technique for maximum test confidence.

Review of NDT documentation

In reviewing or carrying out an audit of NDT reports certain aspects apply to all reports whilst others are specific to a particular technique.

General requirements:

- Date/ time/stage of inspection.
- Place of inspection.
- Procedure or Standard to which the test was performed.
- Standard used for acceptance criteria.
- Material type and thickness.
- Joint configuration.
- All defects identified, located and sized.
- NDT technicians name and qualification.
- Stamped signed and dated.

Ultrasonic specific – note not suitable for all weld metal types

- Surface finish ie as-welded or ground.
- Type of equipment.
- Probe types – compression and shear wave.
- Probe sizes – usually 10mm.
- Probe frequency – typically 2.5–5MHz.
- Probe angles – typically 45, 60, 70, 90.
- Type of couplant.
- Calibration block type and hole size.
- Calibration range setting.
- Scanning pattern.
- Sensitivity setting.
- Recording level.

Radiographic specific

- Type of radiation – X or gamma
- Source type, size and strength (curies)
- Tube focal spot size and power (Kva)
- Technique eg single wall single image
- Source/focal spot to film distance
- Type and range of IQI.
- Type and size of film.
- Type and placement of intensifying screens.
- Exposure time.
- Development temps and times.
- Recorded sensitivity – better than 2%.
- Recorded density range – 2-3.5.

Magnetic particle specific – note method suitable for ferritic steels only

- Method – wet/dry, fluorescent, contrast, etc.
- Method of magnetisation- DC or AC.
- Equipment type – prod, yoke, perm. magnet, bench, coils.
- Prod spacing (7.5A/mm).
- Lift test for magnets – 4.5kg for AC yoke, 18kg for perm. Magnet.
- Contrast paint.
- Ink type.
- Prod/yoke test scan sequence – 2 x at 45° to weld c/l.
- Lighting conditions – 500 Lux min for daylight, 20 Lux for UV.
- UV light -1mW/cm².
- Flux measurement strips – Burmah-Castrol, etc.

Penetrant specific

- Method – colour contrast or fluorescent.
- Surface preparation.
- Penetrant type.
- Application method and time (5-60min).
- Method of removal.
- Type and application of developer.
- Contrast light – 500 Lux min.
- Black light – 20 Lux.
- Operating temperature - 5–50°C.

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NDT

Section 14

Materials Joining and Engineering Technologies
Training and Examination Services

TWI

Non-Destructive Testing

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

Four basic NDT methods

- Magnetic particle inspection (MT).
- Dye penetrant inspection (PT).
- Radiographic inspection (RT).
- Ultrasonic inspection (UT).

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Radiographic Testing

The principles of radiography

- X or Gamma radiation is imposed upon a test object.
- Radiation is transmitted to varying degrees dependant upon the density of the material through which it is travelling.
- Thinner areas and materials of a less density show as darker areas on the radiograph.
- Thicker areas and materials of a greater density show as lighter areas on a radiograph.
- Applicable to metal's, non-metals and composites.

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Radiographic Testing



X-rays
Electrically generated

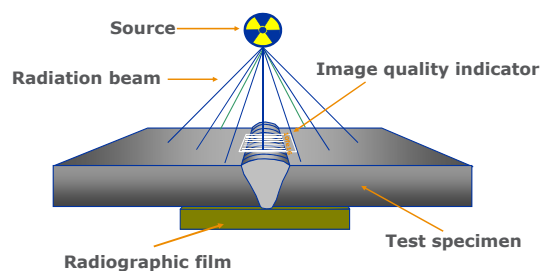


Gamma rays
Generated by the decay of unstable atoms

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Radiographic Testing



Source

Radiation beam

Image quality indicator

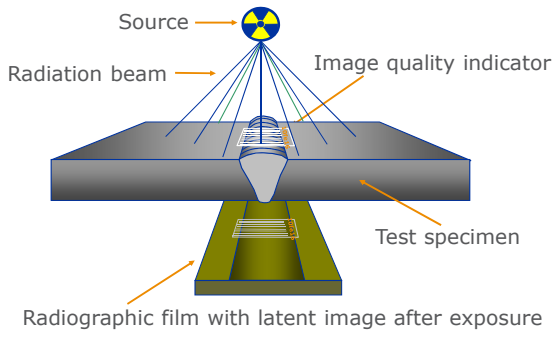
Test specimen

Radiographic film

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Radiographic Testing



Source

Radiation beam

Image quality indicator

Test specimen

Radiographic film with latent image after exposure

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Radiographic Testing

Density - relates to the degree of darkness.
Contrast - relates to the degree of difference.
Definition - relates to the degree of sharpness.
Sensitivity - relates to the overall quality of the radiograph.

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Radiographic Density



Density strip

- Density is measured by a densitometer.
- A densitometer should be calibrated using a density strip.



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Radiographic Sensitivity

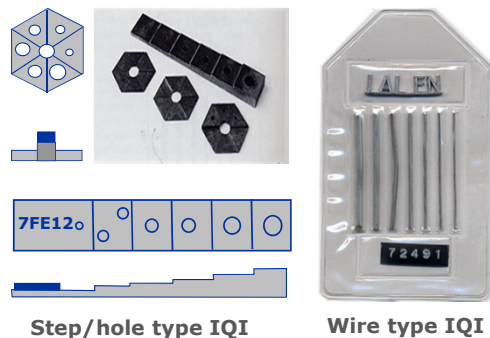
IQI's/Penetrators are used to measure radiographic sensitivity and the quality of the radiographic technique used.

They are not used to measure the size of defects detected.

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Radiographic Sensitivity



Step/hole type IQI

Wire type IQI

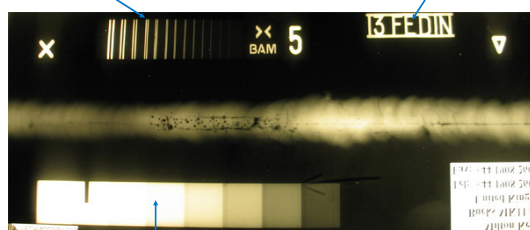
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Radiographic Sensitivity

Duplex type IQI

Wire type IQI

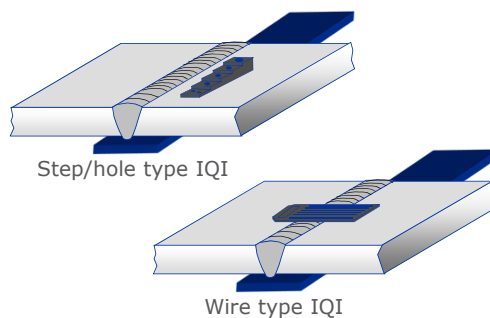


Step/Hole type IQI

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Radiographic Sensitivity



Step/hole type IQI

Wire type IQI

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Radiographic Techniques

Single Wall Single Image (SWSI)

- Film inside, source outside.

Single Wall Single Image (SWSI) panoramic

- Film outside, source inside (internal exposure).

Double Wall Single Image (DWSI)

- Film outside, source outside (external exposure).

Double Wall Double Image (DWDI)

- Film outside, source outside (elliptical exposure).

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Single Wall Single Image (SWSI)

IQI's should be placed source side

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Single Wall Single Image Panoramic

- IQI's are placed on the film side.
- Source inside film outside (single exposure).

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Double Wall Single Image (DWSI)

- IQI's are placed on the film side.
- Source outside film outside (multiple exposure).
- This technique is intended for pipe diameters over 100mm.

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Double Wall Double Image (DWDI)

- IQI's are placed on the source or film side.
- Source outside film outside (multiple exposure).
- A minimum of two exposures.
- This technique is intended for pipe diameters less than 100mm.

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Gamma Isotopes

Isotope	Typical thickness range
Iridium 192	10 to 70 mm
Cobalt 60	> 50 mm
Ytterbium 169	<10 mm
Thulium 170	< 10 mm
Selenium 75	10 to 40mm

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Gamma Isotopes Half Life

The half life of an isotope is the time taken for an isotope to reduce its initial activity by a half. After two half life's the activity is reduced to one quarter of its initial activity. Isotopes are normally replaced after 3 half life's.

- | | |
|-----------------|------------|
| ▪ Cobalt 60 | 5.3 years. |
| ▪ Iridium 192 | 74 days. |
| ▪ Ytterbium 169 | 32 days. |
| ▪ Selenium 75 | 120 days. |

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Radiographic Testing

Lead intensification screens (Pb)

- < 100 Kv's None or up to 0.03mm thickness.
- 100 to 250 KV's up to 0.15mm thickness.
- > 250 KV's / Ir192 up to 0.2mm thickness.
- Co60 0.25 to 0.7mm thickness.

Source Size

- Ir192 1.5 X 1.5 17Ci, 2.0 X 2.0 60Ci, 3 X 2 120Ci 4 X 4 300Ci.

Processing

- Development typically 4minutes at 20°C.
- Fixing typically around 2-4 minutes at 20°C.

Density typically 2 to 3.5.

Sensitivity typically 2% or less.

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Radiographic Testing

Advantages

- Permanent record.
- Little surface preparation.
- Defect identification.
- No material type limitation.
- Not so reliant upon operator skill.
- Thin materials.

Disadvantages

- Expensive consumables.
- Bulky equipment.
- Harmful radiation.
- Defect require significant depth in relation to the radiation beam (not good for planar defects).
- Slow results.
- Very little indication of depths.
- Access to both sides required.

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Ultrasonic Testing



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Ultrasonic Testing

Main features

- Surface and sub-surface detection.
- This detection method uses high frequency sound waves, typically above 2MHz to pass through a material.
- A probe is used which contains a piezo electric crystal to transmit and receive ultrasonic pulses and display the signals on a cathode ray tube or digital display.
- The actual display relates to the time taken for the ultrasonic pulses to travel the distance to the interface and back.
- An interface could be the back of a plate material or a defect.
- For ultrasound to enter a material a couplant must be introduced between the probe and specimen.

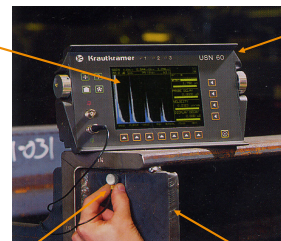
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Ultrasonic Testing

Pulse echo signals
A scan display

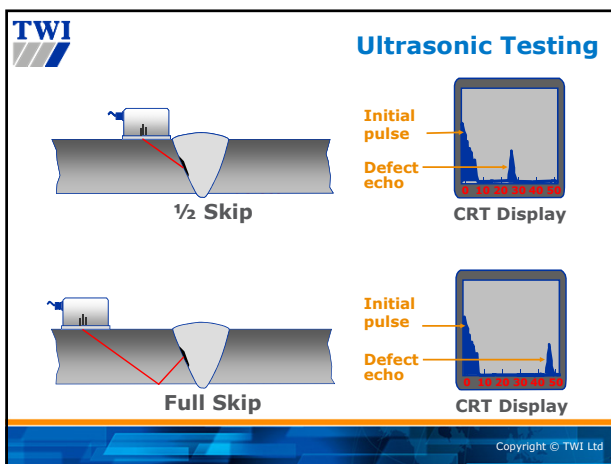
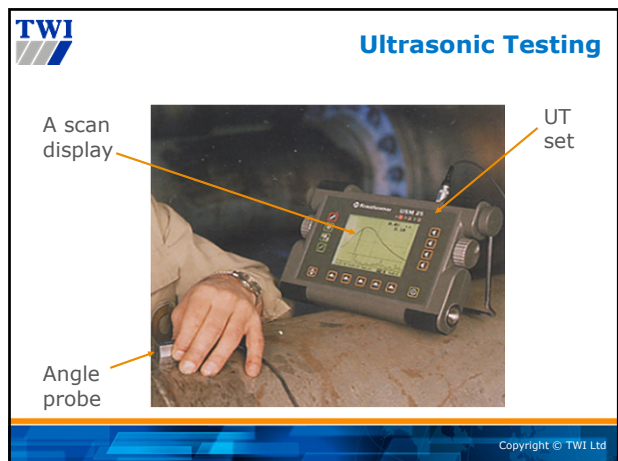
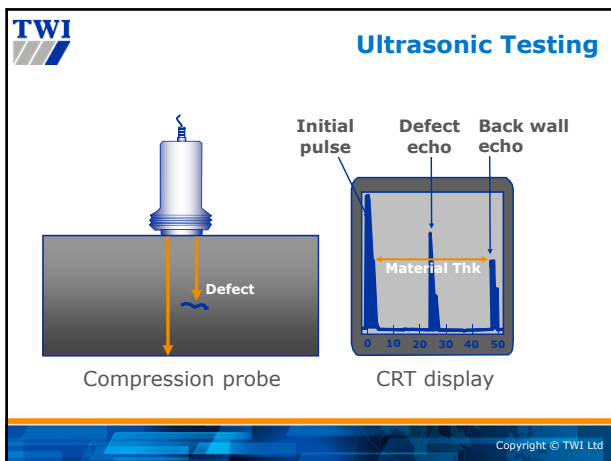
Digital
UT set



Compression probe

Checking the material thickness

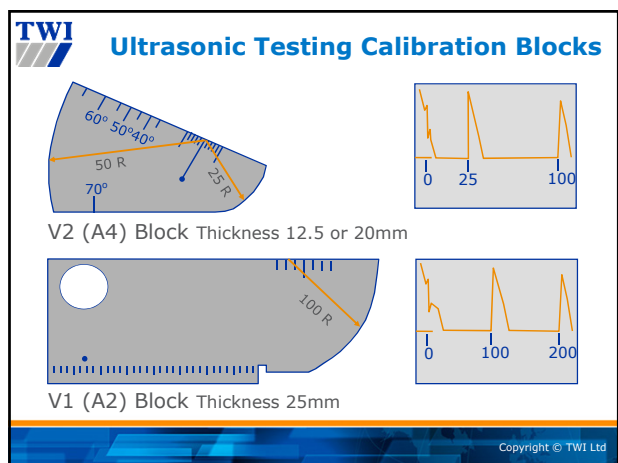
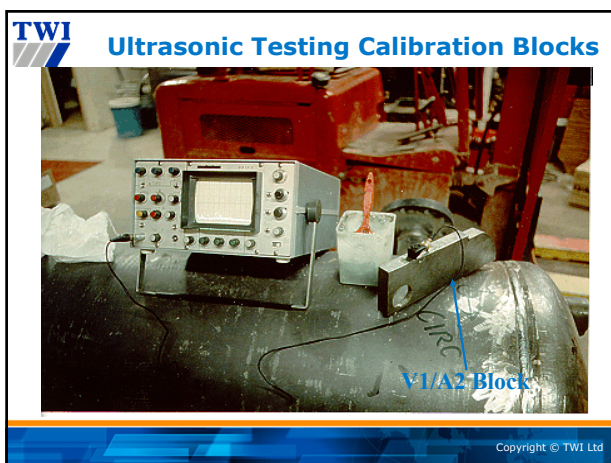
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TWI **Ultrasonic Testing Probes**

Probes	Frequency	Crystal	Application
0°	4 to 5 MHz	Twin 10mm	Lamination scanning, weld scanning if cap ground flush
45°	4 to 5 MHz	Single 10mm	Weld body scanning root pass and plate thickness above 15mm
60°	4 to 5 MHz	Single 10mm	Weld body scanning plate thickness above 10mm
70°	4 to 5 MHz	Single 10mm	Weld body scanning all plate thickness

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Ultrasonic Testing

Advantages

- Rapid results.
- Both surface and sub-surface detection.
- Safe.
- Capable of measuring the depth of defects.
- May be battery powered.
- Portable.

Disadvantages

- Trained and skilled operator required.
- Requires high operator skill.
- Good surface finish required.
- Defect identification.
- Couplant may contaminate.
- No permanent record.
- Calibration Required.
- Ferritic material (mostly).

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Magnetic Particle Testing



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Magnetic Particle Testing

Main features

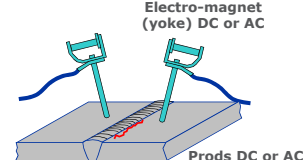
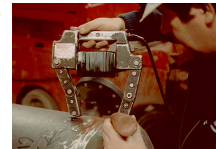
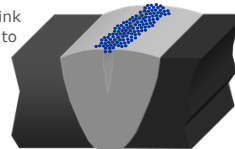
- Surface and slight sub-surface detection.
- Relies on magnetization of component being tested.
- Only Ferro-magnetic materials can be tested.
- A magnetic field is introduced into a specimen being tested.
- Methods of applying a magnetic field, yoke, permanent magnet, prods and flexible cables.
- Fine particles of iron powder are applied to the test area.
- Any defect which interrupts the magnetic field, will create a leakage field, which attracts the particles.
- Any defect will show up as either a dark indication or in the case of fluorescent particles under UV-A light a green/yellow indication.

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Magnetic Particle Testing

Collection of ink particles due to leakage field



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Magnetic Particle Testing

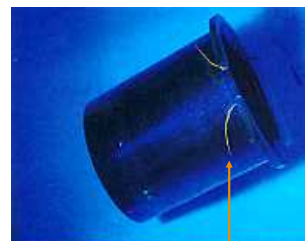
A crack like indication



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Magnetic Particle Testing



Crack like indication

Alternatively to contrast inks, fluorescent inks may be used for greater sensitivity.

These inks require a UV-A light source and a darkened viewing area to inspect the component.

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Magnetic Particle Testing

Typical sequence of operations to inspect a weld

- Clean area to be tested.
- Apply contrast paint.
- Apply magnetism to the component.
- Apply ferro-magnetic ink to the component during magnetising.
- Interpret the test area.
- Post clean and de-magnetise if required.

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Magnetic Particle Testing

Magnetic ink composition

- Non-fluorescent ink between 1.25% to 3.5% by volume.
- Fluorescent ink between 0.1% to 0.3% by volume.

Light requirements

- White light 500 Lux minimum.
- Black light 20 Lux or 1.0mW/cm².

Permanent/electromagnets lifting capacity

- AC current 4.5 kg pole spacing 300mm or less.
- DC current 18 kg pole spacing above 75mm.

Prods

- 6 amps/mm of spacing i.e. 200mm spacing = 1200 amps.

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Magnetic Particle Testing

Advantages

- Simple to use.
- Inexpensive.
- Rapid results.
- Little surface preparation required.
- Possible to inspect through thin coatings.

Disadvantages

- Surface or slight sub-surface detection only.
- Magnetic materials only.
- No indication of defects depths.
- Only suitable for linear defects.
- Detection is required in two directions.

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Penetrant Testing



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Penetrant Testing

Main features

- Detection of surface breaking defects only.
- This test method uses the forces of capillary action.
- Applicable on any material type, as long they are non porous.
- Penetrants are available in many different types:
 - Water washable contrast.
 - Solvent removable contrast.
 - Water washable fluorescent.
 - Solvent removable fluorescent.
 - Post-emulsifiable fluorescent.

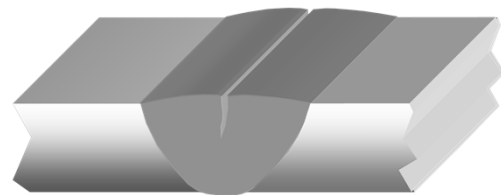
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Penetrant Testing

Step 1. Pre-cleaning

Ensure surface is very clean normally with the use of a solvent.

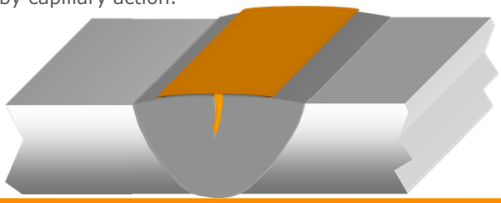


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Penetrant Testing

Step 2. Apply penetrant
After the application, the penetrant is normally left on the components surface for approximately 5-15 minutes (dwell time). The penetrant enters any defects that may be present by capillary action.

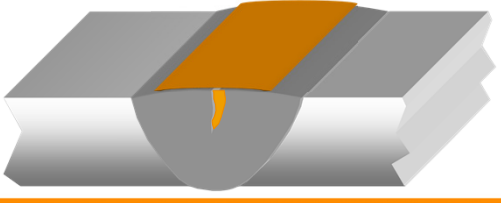


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Penetrant Testing

Step 3. Clean off penetrant
The penetrant is removed after sufficient penetration time (dwell time). Care must be taken not to wash any penetrant out/off any defects present.

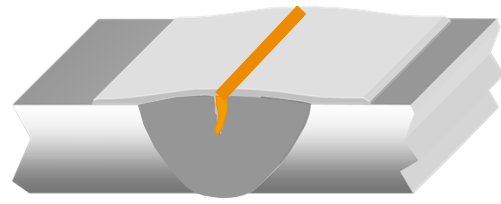


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Penetrant Testing

Step 4. Apply developer
After the penetrant has been cleaned sufficiently, a thin layer of developer is applied. The developer acts as a contrast against the penetrant and allows for reverse capillary action to take place.

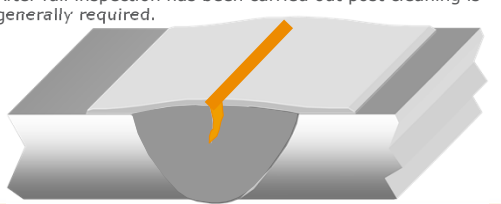


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Penetrant Testing

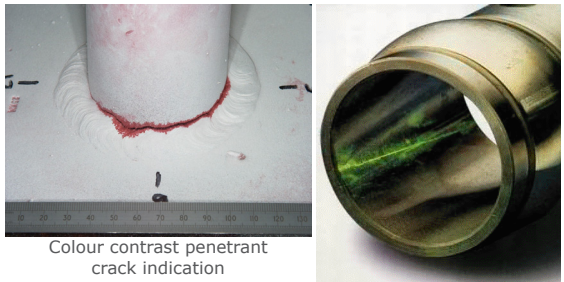
Step 5. Inspection/development time
Inspection should take place immediately after the developer has been applied. Any defects present will show as a bleed out during development time. After full inspection has been carried out post cleaning is generally required.



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Penetrant Testing



Colour contrast penetrant crack indication

Fluorescent penetrant crack indication

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Penetrant Testing

Test procedure

- Penetrant time 5-15 minutes.
- Development/inspection time 0-30 minutes.

Light requirements

- White light 500 Lux minimum.
- Black light 20 Lux or 1.0mW/cm², below 20 Lux ambient light.
- Inspectors should wait 5 minutes before conducting inspection using fluorescent methods to allow the eyes to become adapted to the conditions.

Temperature

- Between 10-50°C.

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Penetrant Testing

Advantages

- Simple to use.
- Inexpensive.
- Quick results.
- Can be used on any non-porous material.
- Portability.
- Low operator skill required.

Disadvantages

- Surface breaking defect only.
- Little indication of depths.
- Penetrant may contaminate component.
- Surface preparation critical.
- Post cleaning required.
- Potentially hazardous chemicals.
- Can not test unlimited times.
- Temperature dependant.

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Any Questions



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NDT Specification Exercise

Please turn to appendix 2 in your course notes (A2-1), here you will find four NDT reports accompanied by five questions for each report relating to the NDT method and referencing the TWI specification in most cases.

There will be one correct answer for each question.

Note! Answers will be shown on screen using PowerPoint section 14A after students have completed the exercise.

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Section 15

Welding Consumables

15 Welding Consumables

Welding consumables are defined as all those things that are used up in the production of a weld.

This list could include many things including electrical energy; however we normally refer to welding consumables as those things used up by a particular welding process.

15.1 MMA electrodes

MMA electrodes can be categorised according to the type of covering they have and consequently the characteristics that it confers.

For C-Mn and low alloy steels there are 3 generic types of electrodes:

- Cellulosic.
- Rutile.
- Basic.

These generic names indicate the type of mineral/compound that is dominant in the covering.

15.1.1 Covered electrode manufacture

Electrode manufacturers produce electrodes by:

- Straightening and cutting core wire to standard lengths (typically 300, 350 and 450mm depending on electrode classification and diameter).
- Making a dry mix of powdered compounds/minerals (precise levels of additions depend on individual manufacturer's formulations).
- Making a wet mix by adding the dry powders to a liquid binder.
- Extruding the covering (concentrically) on to the core wire.
- Hardening the covering by drying the electrodes.*
- Carrying out batch tests - as required for electrode certification.
- Packing the electrodes into suitable containers.

* For low hydrogen electrodes this is a high temperature bake - $\geq 450^{\circ}\text{C}$.

- Vacuum packed electrodes are packed in small quantities into packaging that is immediately vacuum sealed – to ensure no moisture pick-up.
- Electrodes that need to be re-baked are packed into standard packets and as this may be some time after baking, and the packaging may not be sealed, they do not reach the end-user in a guaranteed low hydrogen condition, they therefore require re-baking at a typical temperature of 350°C for approximately 2 hours,

Note! You should always follow the manufacturer's recommendations.

For individual batch certification this will require the manufacture of a test pad for chemical analysis and may require manufacture of a test weld from which a tensile test and Charpy V notch test pieces are tested.

15.1.2 Electrode coverings

Core wires used for most C-Mn electrodes, and some low alloy steel electrodes, are a very low C steel* and it is the formulation of the covering that determines the composition of the deposited weld metal and the operating characteristics of the electrode.

(* typically ~ 0.06%C, ~0.5%Mn)

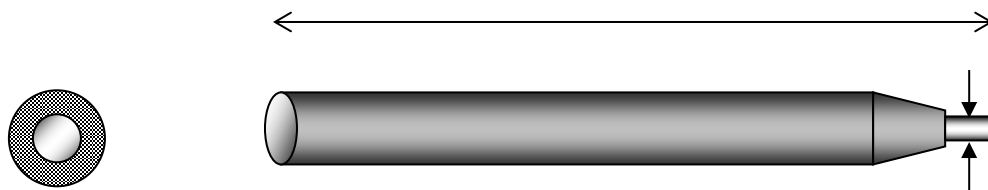
The flux covering on an electrode is formulated to aid the manufacturing process and to provide a number of functions during welding.

The major welding functions are:

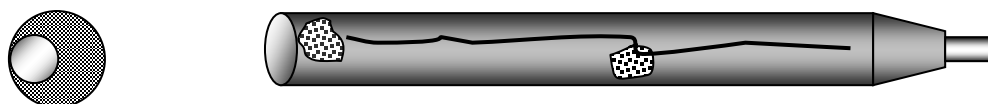
- Facilitate arc ignition/re-ignition and give arc stabilisation.
- Generate gas for shielding the arc and molten metal from contamination by air.
- Interact with the molten weld metal to give de-oxidation and flux impurities into the slag to cleanse/refine the molten weld metal.
- Form a slag for protection of the hot weld metal from air contamination.
- Provide elements to give the weld metal the required mechanical properties.
- Enable positional welding by means of slag formers that freeze at temperatures above the solidification temperature range of the weld metal.

15.1.3 Inspection points for MMA consumables

1. Size: Wire diameter and length.



2. Condition: Cracks, chips and concentricity.



3. Type (specification): Correct specification/code.



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 at **150°C** 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 temperature and humidity.

15.2 Cellulosic electrodes

Cellulose is the principal substance in this type of electrode and comprising typically ~ 40% of the flux constituents.

Cellulose is an organic material (naturally occurring) such as cotton and wood, but it is wood pulp that is the principal source of cellulose used in the manufacture of electrode coverings.

The main characteristics of cellulosic electrodes are:

- Cellulose breaks down during welding and produces carbon monoxide and dioxide and hydrogen.
- Hydrogen provides part of the gas shielding function and gives a relatively high arc voltage.
- The high arc voltage gives the electrode a hard and forceful arc with good penetration/fusion ability.
- The volume of slag formed is relatively small.
- Cellulosic electrodes cannot be baked during manufacture or before welding because this would destroy the cellulose; the manufacturing procedure is to harden the coating by drying (typically at 70-100°C).
- Because of the high hydrogen levels there is always some risk of H cracking which requires control measures such as hot-pass welding to facilitate the rapid escape of hydrogen.
- Because of the risk of H cracking there are limits on the strength/ composition and thickness of steels on which they can be used (electrode are manufactured in classes E60xx, E70xx, E80xx and E90xx but both lower strength grades tend to be the most commonly used).
- High toughness at low temperatures cannot be consistently achieved from this type of electrode (typically only down to about -20°C).

15.2.1 Applications of cellulosic electrodes

Cellulosic electrodes have characteristics that enable them to be used for vertical-down welding at fast travel speed but with low risk of lack-of-fusion because of their forceful arc.

The niche application for this type of electrode is girth seam welding of large diameter steel pipes for overland pipelines (Transco (BGAS) P2, BS 4515 and API 1104 applications). No other type of electrode has the ability to allow root pass welding at high speed and still give good root penetration when the root gap is less than ideal.

Because of their penetration ability these electrodes have also found application on oil storage tanks – for vertical and circumferential seam welding of the upper/thinner courses for which preparations with large root faces or square edge preparations are used.

15.3 Rutile electrodes

Rutile is a mineral that consists of about 90% titanium dioxide (TiO_2) and is present in C and C-Mn steel rutile electrodes at typically ~50%.

Characteristics of rutile electrodes are:

- They have a very smooth and stable arc and produce a relatively thin slag covering that is easy to remove.
- They give a smooth weld profile.
- They are regarded as the most user-friendly of the various electrode types.
- They have relatively high combined moisture content and because they contain typically up to ~10% cellulose they cannot be baked and consequently they do not give a low H weld deposit.
- Because of the risk of cracking they are not designed for welding of high strength or thick section steel.
- (Although electrodes are manufactured in classes E60xx, E70xx, E80xx the E60xx grade is by far the most commonly used).
- They do not give high toughness at low temperatures (typically only down to about -20°C).

The above listed characteristics mean that this type of electrode is used for general-purpose fabrication of unalloyed, low strength steels in relatively thin sections (typically $\leq \sim 13\text{mm}$).

15.3.1 Rutile electrode variants

By adding iron powder to the covering a range of thick-coated electrodes have been produced in order to enhance productivity.

Such electrodes give weld deposits that weigh between ~135 and 190% of their core wire weight and so referred to as high recovery electrodes, or more specifically for example a 170% recovery electrode.

The weld deposit from such electrodes can be relatively large and fluid and this restricts welding to the flat position and for standing fillets for electrodes with the highest recovery rates.

In all other respects these electrodes have the characteristics listed for standard rutile electrodes.

15.4 Basic electrodes

Basic electrodes are so named because the covering is made with a high proportion of basic minerals/compounds (alkaline compounds), such as calcium carbonate (CaCO_3), magnesium carbonate (MgCO_3) and calcium fluoride (CaF_2).

A fully basic electrode covering will be made up with about 60% of these basic minerals/compounds.

Characteristics of basic electrodes are:

- The basic slag that forms when the covering melts reacts with impurities, such as sulphur and phosphorus, and also reduces the oxygen content of the weld metal by de-oxidation.
- The relatively clean weld metal that is deposited gives a very significant improvement in weld metal toughness (C-Mn electrodes with Ni additions can give good toughness down to -90°C).
- They can be baked at relatively high temperatures without any of the compounds present in the covering being destroyed, thereby giving low moisture content in the covering and low hydrogen levels in weld metal.
- In order to maintain the electrodes in a low hydrogen condition they need to be protected from moisture pick-up.
 - By means of baking before use (typically at ~350°C), transferring to a holding oven (typically at ~120°C) and issued in small quantities and/or using heated quivers ('portable ovens') at the work station (typically ~70°.
 - By use of vacuum packed electrodes that do not need to be re-baked before use.
- Basic slag is relatively viscous and thick which means that electrode manipulation requires more skill and should be used with a short arc to minimise the risk of porosity.
- The surface profile of weld deposits from basic electrodes tends to be convex and slag removal requires more effort.

Metal powder electrodes contain an addition of metal powder to the flux coating to increase the maximum permissible welding current level. Thus, for a given electrode size, the metal deposition rate and efficiency (percentage of the metal deposited) are increased compared with an electrode containing no iron powder in the coating. The slag is normally easily removed. Iron powder electrodes are mainly used in the flat and H/V positions to take advantage of the higher deposition rates. Efficiencies as high as 130-140% can be achieved for rutile and basic electrodes without marked deterioration of the arcing characteristics but the arc tends to be less forceful which reduces bead penetration.

15.4.1 Applications of basic electrodes

Basic electrodes have to be used for all applications that require good fracture toughness at temperatures below ~ -20°C.

To avoid the risk of hydrogen cracking basic electrodes have to be used for welding hardenable steels (most C-Mn and all low alloy steels) and for most steels when the joint thickness is greater than about 15mm.

15.5 Classification of electrodes

National standards for electrodes that are used for welding are:

- BS EN ISO 2560 - Covered electrodes for manual metal arc welding of non-alloy and fine grain steels.
- AWS A5.1 - Specification for carbon steel electrodes for shielded metal arc welding.
- AWS A5.5 - Specification for low-alloy steel electrodes for shielded metal arc welding.

Electrode classification is based on tests specified by the standard on weld deposits made with each type of covered electrode. The standards require chemical analysis and mechanical tests and electrode manufacturers tend to dual certify electrodes, wherever possible, to both the European and American standards

15.5.1 BS EN ISO 2560

BS EN ISO 2560 - Covered electrodes for manual metal arc welding of non-alloy and fine grain steels (see Figure 15.1).

This is the designation that manufacturers print on to each electrode so that it can be easily identified. The classification is split into two sections:

Compulsory section - this includes the symbols for:

- Type of product.
- Strength.
- Impact properties.
- Chemical composition.
- Type of electrode covering.

Optional section - this includes the symbols for:

- Weld metal recovery.
- The type of current.
- The welding positions.
- The hydrogen content.

The designation, **compulsory** (strength, toughness and coating including any light alloying elements) must be identified on the electrode, however the **optional** (position, hydrogen levels etc are not **mandatory** and may not be shown on all electrodes.

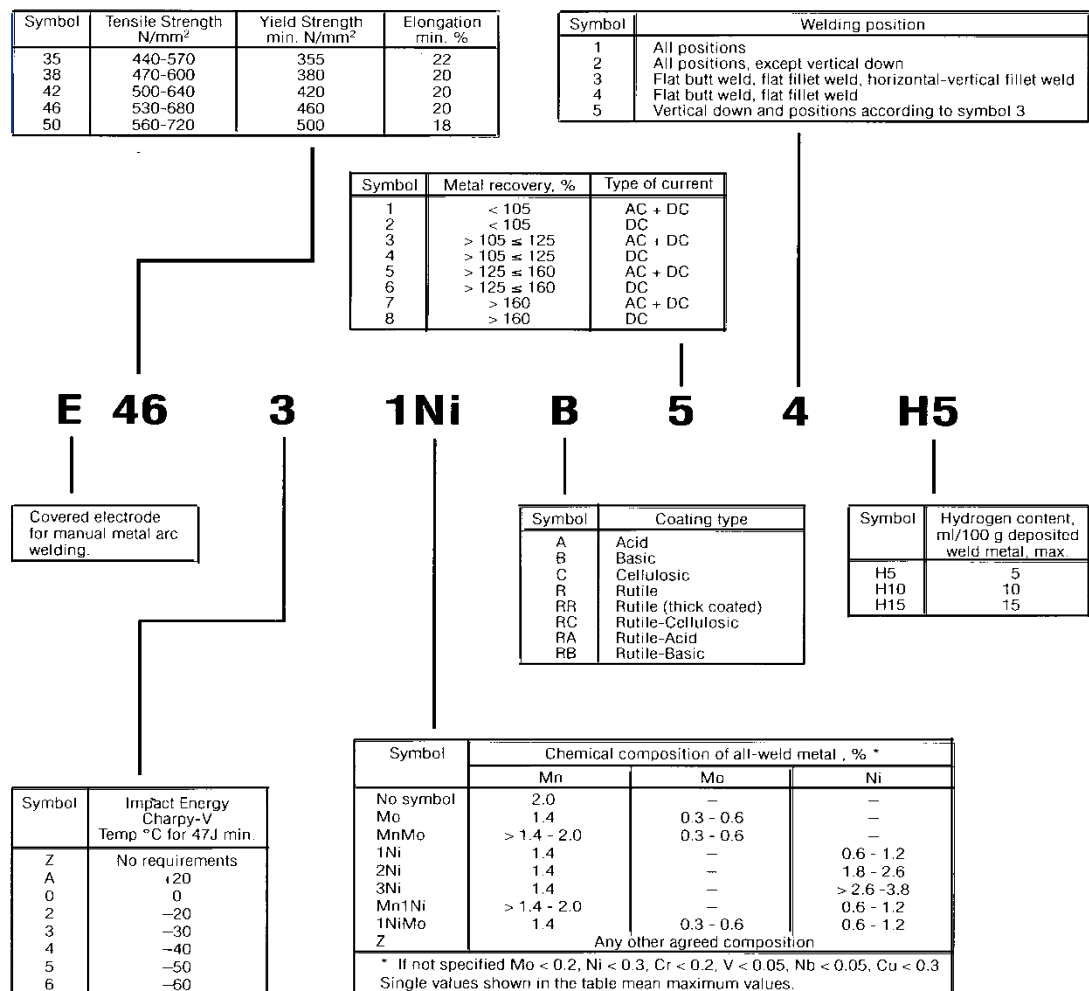


Figure 15.1 The electrode classification system of BS EN ISO 2560.

15.5.2 AWS A5.1/5.1M: 2003

AWS A5.1/5.1M: 2003 - Specification for carbon steel electrodes for shielded metal arc welding (see Figure 15.2).

This specification establishes the requirements for classification of covered electrodes with carbon steel cores for MMA welding. Requirements include mechanical properties of weld metal; weld metal soundness; and usability of electrodes.

Requirements for chemical composition of the weld metal, moisture content of low hydrogen electrodes, standard sizes and lengths, marking, manufacturing and packaging are also included.

A guide to the use of the standard is given in an appendix. Optional supplementary requirements include improved toughness and ductility, lower moisture contents and diffusible hydrogen limits.

The AWS classification system has mandatory and optional designators and requires that both the mandatory classification designators and any optional designators be printed on each electrode. The last two digits of the mandatory part of the classification are used to designate the type of electrode coating/covering and examples of some of the more widely used electrodes are shown below.

Table 15.1 Examples of some of the commonly used AWS A5.1 electrodes.

AWS A5.1 classification	Tensile strength, N / mm²	Type of coating
E6010	414	Cellulosic
E6011		Cellulosic
E6012		Rutile
E6013		Rutile
E7014	482	Rutile, iron powder
E7015		Basic
E7016		Basic
E7018		Basic, iron powder
E7024		Rutile high recovery

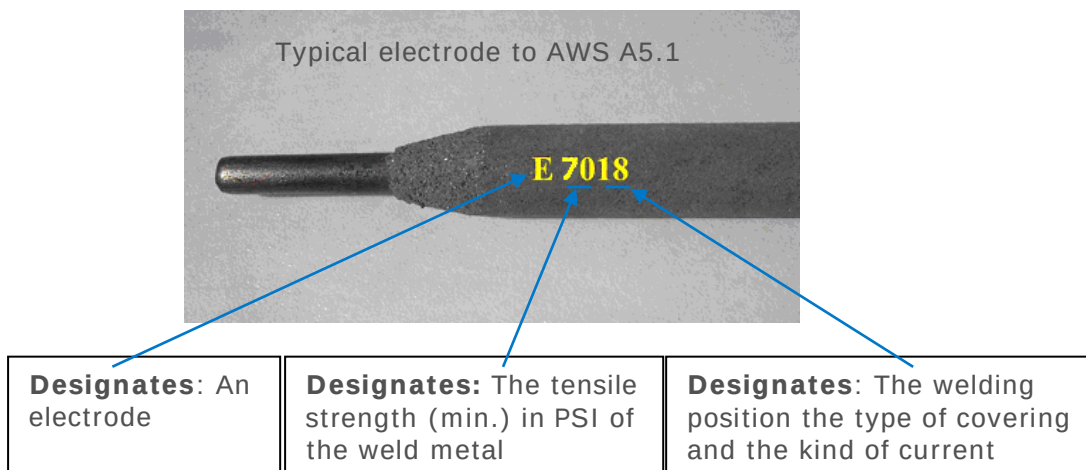


Figure 15.2 Mandatory classification designators.

Table 15.1 Common electrodes that are classified to BS EN ISO 2560 & AWS A5.1 / 5.5.

General description	BS EN ISO 2560	AWS A5.1 / 5.5
Cellulosic electrodes <i>(For vertical-down welding 'Stovepipe welding' of pipeline girth welds)</i>	E 38 3 C 21	E6010
	E 42 3 Z C 21	E7010-G
	E 46 3 Z C 21	E8010-G
	E 42 3 C 25	E7010-P 1 *
	E 46 4 1Ni C 25	E8010-P 1 *
	* P = specially designated piping electrodes	
Rutile electrodes <i>(For general purpose fabrication of low strength steels – can be used for all positions except vertical-down)</i>	E 38 2 R 12	E6013
	E 42 0 R 12	E6013
Heavy coated rutile electrodes (Iron-powder electrodes) <i>(For higher productivity welding for general fabrication of low strength steels – can generally only be used for downhand or standing fillet welding)</i>	E 42 0 RR 13	E6013
	E 42 0 RR 74	E7024
Basic electrodes <i>(For higher strength steels, thicker section steels where there is risk of H cracking; for all applications requiring good fracture toughness)</i>	E 42 2 B 12 H10	E7016
	E 42 4 B 32 H5	E7018
	E 46 6 Mn1Ni B 12 H5	E 7016-G
	E 55 6 Mn1Ni B 32 H5	E8018-C1
	E 46 5 1Ni B 45 H5*	E8018-G
		E9018-G
		E10018-G
	* Vertical-down low H electrodes	

15.6 TIG filler wires

Filler wires manufactured for TIG welding have compositions very similar to those of base materials. However, they may contain very small additions of elements that will combine with oxygen and nitrogen as a means of scavenging any contaminants from the surface of the base material or from the atmosphere.

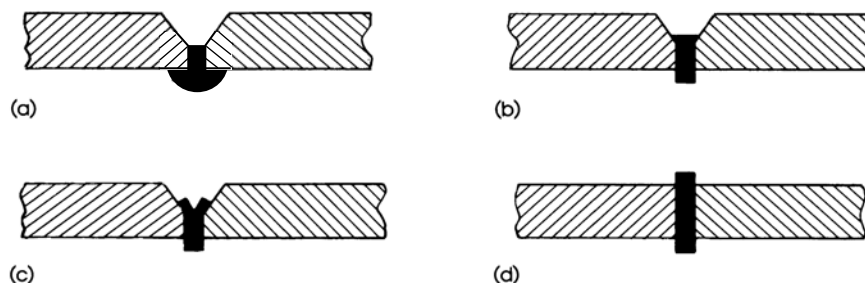
For manual TIG, the wires are manufactured to the BS EN ISO 14341 and are provided in 1m lengths (typically 1.2, 1.6, and 2.4mm diameter) and for identification have flattened ends on which is stamped the wire designation (in accordance with a particular standard) and, for some grades, a batch number.



TIG consumable identification is stamped at the end of the wire.

For making precision root runs for pipe butt welds (particularly for automated TIG welding) consumable inserts can be used that are made from material the same as the base material, or are compatible with it.

For small diameter pipe, the insert may be a ring but for larger diameter pipe an insert of the appropriate diameter is made from shaped strip/wire, examples of which are shown below.



15.6.1 TIG shielding gases

Pure argon is the shielding gas that is used for most applications and is the preferred gas for TIG welding of steel and gas flow rates are typically ~8-12 litres/min for shielding.

The shielding gas not only protects the arc and weld pool but also is the medium required to establish a stable arc by being easy to ionise. A stable arc cannot be established in air and hence the welder would not be able to weld if the shielding gas were not switched on.

Argon with a helium addition – typically ~30% may be used when a hotter arc is needed such as when welding metals with high thermal conductivity, such as copper/copper alloys or thicker section aluminium/aluminium alloys.

There are some circumstances when special shielding gases are beneficial, for example:

Ar + 3-5%H for austenitic stainless steels and Cu-Ni alloys.

Ar + ~3%N for duplex stainless steels.

15.6.2 TIG back-purging

For most materials, the underside of a weld root bead needs to be protected by an inert gas (a back-purge) – typically ~6-8 litres/min during welding.

For C steels and low alloy steels with total alloying additions $\leq 2.5\%$ it may not always be necessary to use a back-purge but for higher alloyed steels and most other materials there may be excessive oxidation – and risk of lack of fusion if it is not used.

15.7 MIG/MAG filler wires

Solid filler wires manufactured for MIG/MAG generally have chemical compositions that have been formulated for particular base materials and the wires have compositions similar to these base materials. Solid wires for welding steels with active shielding gases are deoxidised with manganese and silicon to avoid porosity. There may also be titanium and aluminium additions.

Mild steel filler wires are available with different levels of deoxidants, known as double or triple de-oxidised wires. More highly deoxidised wires are more expensive but are more tolerant of the plate surface condition, eg mill scale, surface rust, oil, paint and dust. There may, therefore, be a reduction in the amount of cleaning of the steel before welding.

These deoxidiser additions yield a small amount of glassy slag on the surface of the weld deposit, commonly referred to as silica deposits. These small pockets of slag are easily removed with light brushing; but when galvanising or painting after welding, it is necessary to use shot blasting.

During welding, it is common practice to weld over these small islands since they do not represent a thick slag, and they usually spall off during the contraction of the weld bead. However, when multipass welding, the slag level may build up to an unacceptable level causing weld defects and unreliable arc starting.

Steel wires usually have a flash coating of copper to improve current pick-up and to extend the shelf life of the wire. However, the copper coating can sometimes flake off and be drawn into the liner and wire feed mechanism, particularly if there is misalignment in the wire feed system. This may cause clogging and erratic wire feed.

Uncoated wires are available as an alternative, although electrical contact may not be as good as with copper-coated wires, and contact tip operating temperatures may be higher.

Some typical Standards for specification of steel wire consumables are:

BS EN ISO 14341

Welding consumables - Wire electrodes and deposits for gas shielded metal arc welding of non-alloy and fine grain steels - Classification.

BS EN ISO 16834

Welding consumables - Wire electrodes, wires, rods and deposits for gas shielded metal arc welding of high strength steels - Classification.

Wire sizes are typically in the range 0.6-2.4mm diameter but the most commonly used sizes are 0.8, 1, 1.2 and 1.6mm and provided on layer wound spools for consistent feeding.

Spools should be labelled to show the classification of the wire and its' diameter.

Flux-cored and metal-cored wires are also used extensively although the process is then referred to as **FCAW** (flux-cored arc welding) and **MCAW** (metal cored arc welding)

15.7.1 MIG/MAG gas shielding

For non-ferrous metals and their alloys (such as Al, Ni and Cu) an inert shielding gas must be used. This is usually either pure argon or an argon rich gas with a helium addition.

The use of a fully inert gas is the reason why the process is also called **MIG** welding (**metal inert gas**) and for precise use of terminology this name should only be used when referring to the welding of non-ferrous metals.

The addition of some helium to argon gives a more uniform heat concentration within the arc plasma and this affects the shape of the weld bead profile.

Argon-helium mixtures effectively give a hotter arc and so they are beneficial for welding thicker base materials those with higher thermal conductivity eg copper or aluminium.

For welding of steels – all grades, including stainless steels – there needs to be a controlled addition of oxygen or carbon dioxide in order to generate a stable arc and give good droplet wetting. Because these additions react with the molten metal they are referred to as active gases and hence the name **MAG** welding (**metal active gas**) is the technical term that is use when referring to the welding of steels.

The percentage of carbon dioxide (CO₂) or oxygen depends on the type of steel being welded and the mode of metal transfer being used – as indicated below:

- 100%CO₂
For low carbon steel to give deeper penetration (Figure 15.3) and faster welding this gas promotes globular droplet transfer and gives high levels of spatter and welding fume.
- Argon + 15 to 25%CO₂
Widely used for carbon and some low alloy steels (and FCAW of stainless steels).
- Argon + 1 to 5%O₂
Widely used for stainless steels and some low alloy steels.

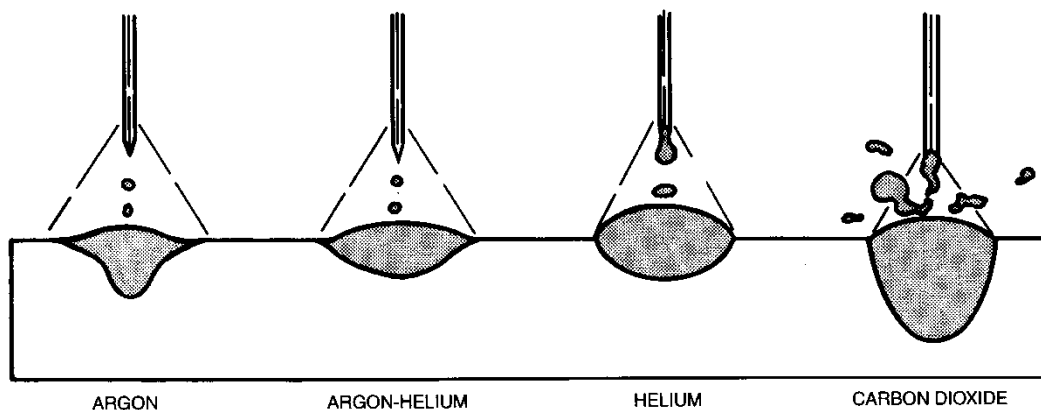


Figure 15.3 Effects of shielding gas composition on weld penetration and profile.

Material thickness (mm): 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15+																
Dip transfer																
Argon-CO ₂ mixtures		2-5%	5-10%	10-15%	20-25% CO ₂											
CO ₂																
Spray transfer																
Argon-CO ₂ mixtures				5-10%	10-15%	15-20% CO ₂										
Argon-O ₂ mixtures																
Pulse transfer																
Argon-CO ₂ mixtures				5-10%	10-15% CO ₂											

Figure 15.4 Active shielding gas mixtures for MAG welding of carbon, carbon-manganese and low alloy steels.

Blue is a cooler gas mixture; red is a hotter mixture.

Gas mixtures - helium in place of argon gives a hotter arc, more fluid weld pool and better weld profile. These quaternary mixtures permit higher welding speeds, but may not be suitable for thin sections.

Stainless steels

Austenitic stainless steels are typically welded with argon-CO₂/O₂ mixtures for spray transfer, or argon-helium-CO₂ mixtures for all modes of transfer. The oxidising potential of the mixtures are kept to a minimum (2-2.5% maximum CO₂ content) in order to stabilise the arc, but with the minimum effect on corrosion performance. Because austenitic steels have a high thermal conductivity, the addition of helium helps to avoid lack of fusion defects and overcome the high heat dissipation into the material. Helium additions are up to 85%, compared with ~25% for mixtures used for carbon and low alloy steels. CO₂-containing mixtures are sometimes avoided to eliminate potential carbon pick-up.

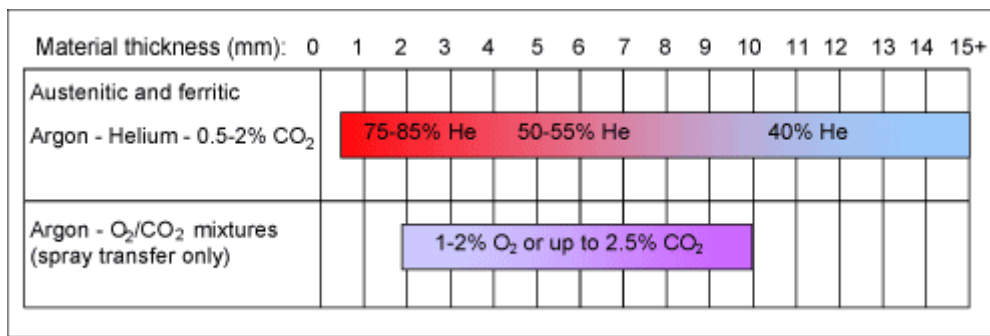


Figure 15.5 Active shielding gas mixtures for MAG welding of stainless steels.

Blue is a cooler gas mixture; red is a hotter mixture.

For martensitic and duplex stainless steels, specialist advice should be sought. Some Ar-He mixtures containing up to 2.5%N₂ are available for welding duplex stainless steels.

Light alloys, eg aluminium and magnesium, and copper and nickel and their alloys

Inert gases are used for light alloys and alloys that are sensitive to oxidation. Welding grade inert gases should be purchased rather than commercial purity to ensure good weld quality.

Argon

Argon can be used for aluminium because there is sufficient surface oxide available to stabilise the arc. For materials that are sensitive to oxygen, such as titanium and nickel alloys, arc stability may be difficult to achieve with inert gases in some applications.

The density of argon is approximately 1.4 times that of air. Therefore, in the downhand position, the relatively heavy argon is very effective at displacing air. A disadvantage is that when working in confined spaces, there is a risk of argon building up to dangerous levels and asphyxiating the welder.

Argon-helium mixtures

Argon is most commonly used for MIG welding of light alloys, but some advantage can be gained by the use of helium and argon/helium mixtures. Helium possesses a higher thermal conductivity than argon. The hotter weld pool produces improved penetration and/or an increase in welding speed. High helium contents give a deep broad penetration profile, but produce high spatter levels. With less than 80% argon, a true spray transfer is not possible. With globular-type transfer, the welder should use a 'buried' arc to minimise spatter.

Arc stability can be problematic in helium and argon-helium mixtures, since helium raises the arc voltage, and therefore there is a larger change in arc voltage with respect to arc length. Helium mixtures require higher flow rates than argon shielding in order to provide the same gas protection.

There is a reduced risk of lack of fusion defects when using argon-helium mixtures, particularly on thick section aluminium. Ar-He gas mixtures will offset the high heat dissipation in material over about 3mm thickness.

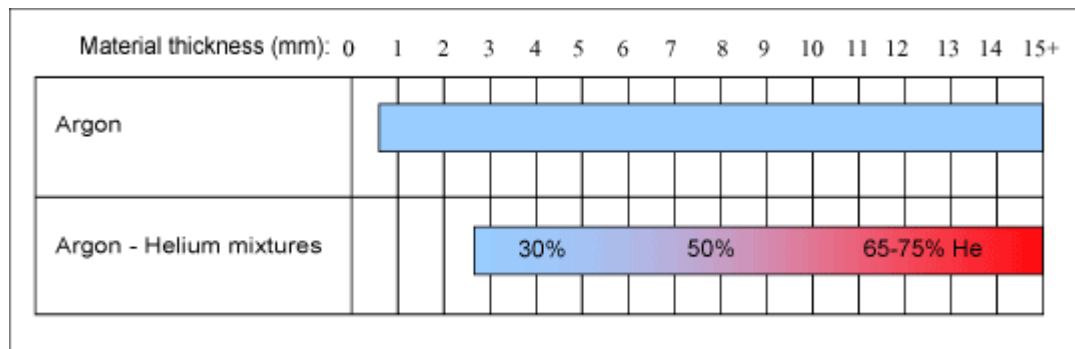


Figure 15.6 Inert shielding gas mixtures for MIG welding of aluminium, magnesium, titanium, nickel and copper alloys.

Blue is a cooler gas mixture; red is a hotter mixture.

A summary table of shielding gases and mixtures used for different base materials is given in Table 15.2.

Summary

Table 15.2 Shielding gas mixtures for MIG/MAG welding – summary

Metal	Shielding gas	Reaction behaviour	Characteristics
Carbon steel	Argon-CO ₂	Slightly oxidising	Increasing CO ₂ content gives hotter arc, improved arc stability, deeper penetration, transition from finger-type to bowl-shaped penetration profile, more fluid weld pool giving flatter weld bead with good wetting, increased spatter levels, better toughness than CO ₂ . Min 80% argon for axial spray transfer. General-purpose mixture: argon-10-15% CO ₂ .
	Argon-O ₂	Slightly oxidising	Stiffer arc than Ar- CO ₂ mixtures minimises undercutting, suited to spray transfer mode, lower penetration than Ar-CO ₂ mixtures, 'finger'-type weld bead penetration at high current levels. General-purpose mixture: argon-3% CO ₂ .
	Argon-helium-CO ₂	Slightly oxidising	Substitution of helium for argon gives hotter arc, higher arc voltage, more fluid weld pool, flatter bead profile, more bowl-shaped and deeper penetration profile and higher welding speeds, compared with Ar- CO ₂ mixtures. High cost.
	CO ₂	Oxidising	Arc voltages 2-3V higher than Ar-CO ₂ mixtures, best penetration, higher welding speeds, dip transfer or buried arc technique only, narrow working range, high spatter levels, low cost.
Stainless steels	He-Ar-CO ₂	Slightly oxidising	Good arc stability with minimum effect on corrosion resistance (carbon pickup), higher helium contents designed for dip transfer, lower helium contents designed for pulse and spray transfer. General-purpose gas: Ar-40-60%He-2%CO ₂ .
	Argon- O ₂	Slightly oxidising	Spray transfer only, minimises undercutting on heavier sections, good bead profile.
Aluminium, copper, nickel, titanium alloys	Argon	Inert	Good arc stability, low spatter, and general-purpose gas. Titanium alloys require inert gas backing and trailing shields to prevent air contamination.
	Argon-helium	Inert	Higher heat input offsets high heat dissipation on thick sections, lower risk of lack of fusion defects, higher spatter and higher cost than argon.

15.8 SAW filler wires

Filler wires for SAW are made to AWS and EN standards and the most commonly used sizes are 2.4, 3.2, 4 and 5mm diameter and are available for welding a wide range of steels and some non-ferrous applications, they have compositions similar to the base material but for certification standards require flux/wire weld metal deposits to be made for analysis and testing as required

15.8.1 SAW flux types

Fluxes can be categorised into two types, namely fused and agglomerated (agglomerated fluxes are sometimes called bonded fluxes – particularly in the USA).

Fused flux

These types are manufactured by mixing certain suitable minerals/compounds, fusing them together, crushing the solid mass and then sieving the crushed mass to recover granules within a particular size range.

Fused fluxes have the following characteristics/properties:

- Contain a high proportion of silica (up to ~60%) and so the flux granules have similar in appearance to crushed glass – irregular shaped and hard - and have a smooth, and slightly shiny, surface.
- During re-circulation they have good resistance to breaking down into fine particles – referred to as fines.
- Have very low moisture content as manufactured and does not absorb moisture during exposure and so they should always give low hydrogen weld metal.
- Give welds beads with good surface finish and profile and de-slag easily.

The main disadvantage of fused fluxes is that the compounds that give de-oxidation cannot be added so that welds have high oxygen content and so steel weld metal does not have good toughness at sub-zero temperatures.



Agglomerated flux

This is manufactured by mixing fine powdered minerals/compounds, adding a wet binder and further mixing to form flux granules of the required size. These are dried/baked to remove moisture, sieved and packaged in sealed containers to ensure they are in low hydrogen condition when supplied to the user.

Some of the minerals/compounds used in these fluxes cannot be subjected to the high temperatures required to make fused fluxes because they would break down and lose the properties that are needed during welding.

Agglomerated fluxes have the following characteristics:

- Granules tend to be more spherical and have a dull/matt finish.
- Granules are consist of fine powders, weakly held together, and so are quite soft and easily be broken down into fine powders during handling/ re-circulation.
- Some of the compounds and the binder itself, will tend to absorb moisture from the atmosphere if left exposed and a controlled handling procedure* is essential.
- The slag is less fluid than those generated by fused fluxes and the weld bead profile tends to be more convex and more effort is required to remove the slag.

*Agglomerated fluxes are similar to fluxes used for basic covered electrodes and susceptible to moisture pick-up when they are cold and left exposed.

A typical controlled handling practice is to transfer flux from the manufacturer's drum/bag to a heated silo (~120-150°C). This acts like the holding oven for basic electrodes.

Warm flux is transferred to the flux hopper on the machine (usually unheated) and at the end of a shift or when there is to be an interruption in welding, the hopper flux should be transferred to the silo.

The particular advantage of agglomerated fluxes is there ability to give weld metals with low oxygen content and this enables steel weld metal to be produced with good sub-zero toughness.



15.8.2 SAW flux basicity index

Fluxes are often referred to as having a certain basicity or basicity index (BI).

The BI indicates the flux formulation according to the ratio of basic compounds to acid compounds and is used to give an indication of flux/weld reaction and can be interpreted as follows:

- A flux with a BI = 1 has an equal ratio of basic and acid compounds and thus is neither basic nor acid but said to be **neutral**.*
- A flux with BI >1 has **basic** characteristics; fully basic fluxes have BI of ~3-~3.5.
- A flux with BI <1 has acid characteristics.
- Fused and agglomerated fluxes are mixed to produce fluxes referred to as semi-basic.

* In the USA it is customary to use the terms neutral to indicate that the flux has no significant influence on the composition by transfer of elements from flux to weld pool and active to indicate that the flux does transfer some elements.

Fused fluxes have acid characteristics and agglomerated fluxes have basic characteristics.

Although there are EN and AWS standards for flux classification, it is common UK practice to order fluxes by manufacturer name and use this name on WPSs.

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Welding Consumables

Section 15

Materials Joining and Engineering Technologies
Training and Examination Services

TWI

Welding Consumables

Welding consumables are any products that are used up in the production of a weld.

Welding consumables may be

- Covered electrodes, filler wires and electrode wires.
- Shielding or oxy-fuel gases.
- Separately supplied fluxes.
- Fusible inserts.

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Welding Consumable Standards

MMA (SMAW)

- BS EN ISO 2560: Steel electrodes.
- AWS A5.1: Non-alloyed steel electrodes.
- AWS A5.4: Chromium electrodes.
- AWS A5.5: Alloyed steel electrodes.

MIG/MAG (GMAW) TIG (GTAW)

- BS EN ISO 14343: Filler wires.
- BS EN ISO 14341: Wire electrodes.
- AWS A5.9: Filler wires.
- BS EN ISO 14175: Shielding gases.

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Welding Consumable Standards

SAW

- BS 4165: Wire and fluxes.
- BS EN ISO 14171: Wire electrodes.
- BS EN ISO 14174: Fluxes.
- AWS A5.17: Wires and fluxes.

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Welding Consumables



Labels in image:

- Welding fluxes (SAW)
- TIG/PAW rods
- Cored wire
- MIG/MAG solid wire
- SAW strips
- SAW solid wire
- Covered electrodes

Courtesy of ESAB AB

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Welding Consumable Gases

Welding gases

- GMAW, FCAW, TIG, Oxy-fuel.
- Supplied in cylinders or storage tanks for large quantities.
- Colour coded cylinders to minimise wrong use.
- Subject to regulations concerned handling, quantities and positioning of storage areas.



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Welding Consumable Gases

- Moisture content is limited to avoid cold cracking.
- Dew point (the temperature at which the vapour begins to condense) must be checked.



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Welding Consumables

Each consumable is critical in respect to

- Size.
- Classification/supplier.
- Condition.
- Treatments eg baking/drying.
- Handling and storage is critical for consumable control.
- Handling and storage of gases is critical for safety.

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Quality Assurance

Welding consumables

- Filler material must be stored in an area with controlled temperature and humidity.
- Poor handling and incorrect stacking may damage coatings, rendering the electrodes unusable.
- There should be an issue and return policy for welding consumables (system procedure).
- Control systems for electrode treatment must be checked and calibrated; those operations must be recorded.
- Filler material suppliers must be approved before purchasing any material.

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Welding Consumables

MMA Covered Electrodes

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MMA Welding Consumables

The three main electrode covering types used in MMA welding

- Cellulosic** - deep penetration/fusion.
- Rutile** - general purpose.
- Basic** - low hydrogen.

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MMA Welding Consumables



Courtesy of Lincoln Electric

Plastic foil sealed cardboard box

- Rutile electrodes.
- General purpose basic electrodes.

Tin can

- Cellulosic electrodes.



Vacuum sealed pack

- Extra low hydrogen electrodes.



Courtesy of Lincoln Electric

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MMA Welding Consumables

Cellulosic electrodes

- Covering contains cellulose (organic material).
- Produce a gas shield high in hydrogen raising the arc voltage.
- Deep penetration/fusion characteristics enables welding at high speed without risk of lack of fusion.
- Generates high level of fumes and H₂ cold cracking.
- Forms a thin slag layer with coarse weld profile.
- Not require baking or drying (excessive heat will damage electrode covering).
- Mainly used for stove pipe welding.
- Hydrogen content is 80-90ml/100g of weld metal.

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MMA Welding Consumables

Rutile electrodes

- Covering contains TiO₂ slag former and arc stabiliser.
- Easy to strike arc, less spatter, excellent for positional welding.
- Stable, easy-to-use arc can operate in both DC and AC.
- Slag easy to detach, smooth profile.
- Reasonably good strength weld metal.
- Used mainly on general purpose work.
- Low pressure pipework, support brackets.
- Electrodes can be dried to lower H₂ content but cannot be baked as it will destroy the coating.
- Hydrogen content is 25-30ml/100g of weld metal.

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MMA Welding Consumables

High recovery rutile electrodes

Characteristics:

- Coating is bulked out with iron powder.
- Iron powder gives the electrode high recovery.
- Extra weld metal from the iron powder can mean that weld deposit from a single electrode can be as high as 180% of the core wire weight.
- Give good productivity.
- Large weld beads with smooth profile can look very similar to SAW welds.

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MMA Welding Consumables

Basic covering

- Produce convex weld profile and difficult to detach slag.
- Very suitable for high pressure work, thick section steel and for high strength steels.
- Prior to use electrodes should be baked, typically 350°C for 2 hour plus to reduce moisture to very low levels and achieve low hydrogen potential status.

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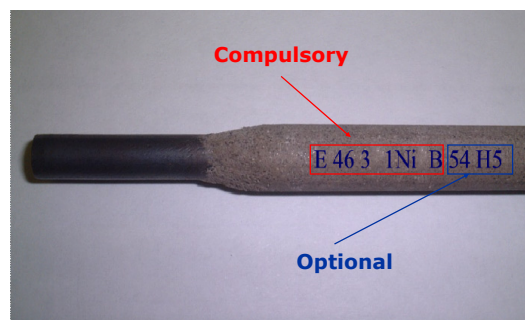
MMA Welding Consumables

- Contain calcium fluoride and calcium carbonate compounds.
- Cannot be rebaked indefinitely!
- Low hydrogen potential gives weld metal very good toughness and YS.
- Have the lowest level of hydrogen (less than 5ml/100g of weld metal).

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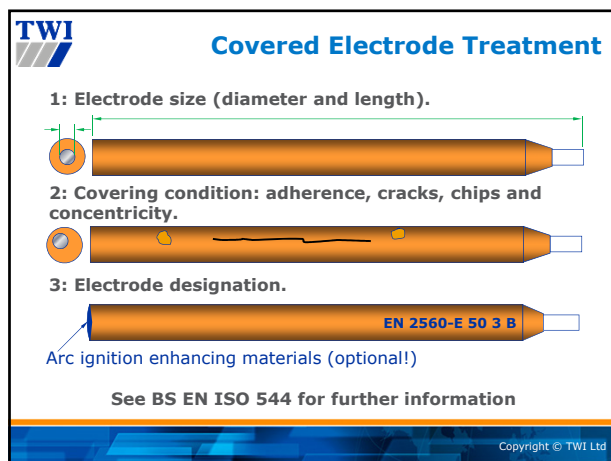
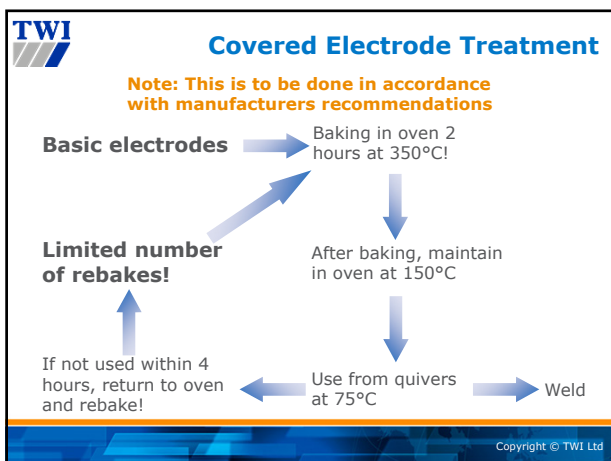
BS EN ISO 2560 MMA Covered Electrodes



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MMA Welding Consumables		
Types of electrodes (for C, C-Mn steels):		
	BE EN ISO 2560	AWS A5.1
Cellulosic	E XX X C	EXX10 EXX11
Rutile	E XX X R	EXX12 EXX13
Rutile heavy coated	E XX X RR	EXX24
Basic	E XX X B	EXX15 EXX16 EXX18

Covered Electrode Treatment	
Cellulosic electrodes	Use straight from the box - No baking/drying!
Rutile electrodes	If necessary, dry up to 120°C - No baking!
Vacuum packed basic electrodes	Use straight from the pack within manufacturers recommendations



Welding Consumables	
TIG Consumables	

TIG Welding Consumables	
Welding consumables for TIG - Filler wires, shielding gases, tungsten electrodes (non-consumable). - Filler wires of different materials composition and variable diameters available in standard lengths, with applicable code stamped for identification. - Steel filler wires of very high quality, with copper coating to resist corrosion. - Shielding gases mainly argon and helium, usually of highest purity (99.9%).	

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TIG Welding Consumables

Welding rods

- Supplied in cardboard/plastic tubes.



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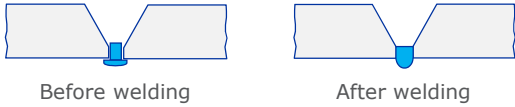
- Must be kept clean and free from oil and dust.
- Might require degreasing.

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Fusible Inserts

Pre-placed filler material



Before welding After welding



Other terms used include

- EB inserts (electric boat company).
- Consumable socket rings (CSR).

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Shielding Gases for TIG Welding

Argon

- Low cost and greater availability.
- Heavier than air - lower flow rates than Helium.
- Low thermal conductivity - wide top bead profile.
- Low ionisation potential - easier arc starting, better arc stability with AC, cleaning effect.
- For the same arc current produce less heat than helium - reduced penetration, wider HAZ.
- To obtain the same arc power, argon requires a higher current - increased undercut.

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Shielding Gases for TIG Welding

Helium

- Costly and lower availability than Argon.
- Lighter than air - requires a higher flow rate compared with argon (2-3 times).
- Higher ionisation potential - poor arc stability with AC, less forgiving for manual welding.
- For the same arc current produce more heat than argon - increased penetration, welding of metals with high melting point or thermal conductivity.
- To obtain the same arc power, helium requires a lower current - no undercut.

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Shielding Gases for TIG Welding

Hydrogen

- Not an inert gas - not used as a primary shielding gas.
- Increase the heat input - faster travel speed and increased penetration.
- Better wetting action - improved bead profile.
- Produce a cleaner weld bead surface.
- Added to argon (up to 5%) - only for austenitic stainless steels and nickel alloys.
- Flammable and explosive.

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Shielding Gases for TIG Welding

Nitrogen

- Not an inert gas.
- High availability - cheap.
- Added to argon (up to 5%) - only for back purge for duplex stainless, austenitic stainless steels and copper alloys.
- Not used for mild steels (age embrittlement).
- Strictly prohibited in case of Ni and Ni alloys (porosity).

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Welding Consumables

MIG/MAG Consumables

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MIG/MAG Welding Consumables

Welding consumables for MIG/MAG

- Spools of continuous electrode wires and shielding gases.
- Variable spool size (1-15Kg) and wire diameter (0.6-1.6mm) supplied in random or orderly layers.
- Basic selection of different materials and their alloys as electrode wires.
- Some steel electrode wires copper coating purpose is corrosion resistance and electrical pick-up.
- Gases can be pure CO₂, CO₂+argon mixes and argon+2%O₂ mixes (stainless steels).

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MIG/MAG Welding Consumables

Welding wires

- Supplied on wire/plastic spools or coils.
- Random or line winding.



Courtesy of Lincoln Electric
Plastic spool



Courtesy of Lincoln Electric
Wire spool



Courtesy of Lincoln Electric
Coil

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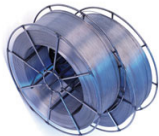
MIG/MAG Welding Consumables

Welding wires

- Carbon and low alloy wires may be copper coated.
- Stainless steel wires are not coated.



Courtesy of Lincoln Electric



Courtesy of ESAB AB

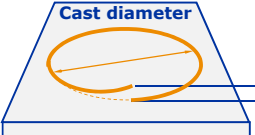
- Wires must be kept clean and free from oil and dust.
- Flux cored wires does not require baking or drying.

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MIG/MAG Welding Consumables

How to check the quality of welding wires



Cast diameter

Helix size - limited to 25mm to avoid problems with arc wandering!

Cast diameter improves the contact force and defines the contact point; usually 400-1200mm.



Contact point close to contact tip end - good!



Contact point remote from contact tip end - poor!

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MIG/MAG Shielding Gases



Ar



Ar-He



He



CO₂

Argon (Ar)

- Higher density than air; low thermal conductivity - the arc has a high energy inner cone; good wetting at the toes; low ionisation potential.

Helium (He)

- Lower density than air; high thermal conductivity - uniformly distributed arc energy; parabolic profile; high ionisation potential.

Carbon dioxide (CO₂)

- Cheap; deep penetration profile; cannot support spray transfer; poor wetting; high spatter.

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MIG/MAG Shielding Gases

Gases for dip transfer

- **CO₂**: Carbon steels only; deep penetration; fast welding speed; high spatter levels.
- **Ar + up to 25% CO₂**: Carbon and low alloy steels; minimum spatter; good wetting and bead contour.
- **90% He + 7,5% Ar + 2,5% CO₂**: Stainless steels; minimises undercut; small HAZ.
- **Ar**: Al, Mg, Cu, Ni and their alloys on thin sections.
- **Ar + He mixtures**: Al, Mg, Cu, Ni and their alloys on thicker sections (over 3mm).

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MIG/MAG Shielding Gases

Gases for spray transfer

- **Ar + (5-18)% CO₂**: Carbon steels; minimum spatter; good wetting and bead contour.
- **Ar + 2% O₂**: Low alloy steels; minimise undercut; provides good toughness.
- **Ar + 2% O₂ or CO₂**: Stainless steels; improved arc stability; provides good fusion.
- **Ar**: Al, Mg, Cu, Ni, Ti and their alloys.
- **Ar + He mixtures**: Al, Cu, Ni and their alloys; hotter arc than pure Ar to offset heat dissipation.
- **Ar + (25-30)% N₂**: Cu alloys; greater heat input.

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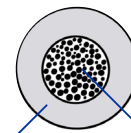
Welding Consumables

Flux Core Wire Consumables

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Flux Core Wire Consumables



Functions of metallic sheath

- Provide form stability to the wire.
- Serves as current transfer during welding.

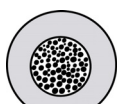
Function of the filling powder

- Stabilise the arc.
- Add alloy elements.
- Produce gaseous shield.
- Produce slag.
- Add iron powder.

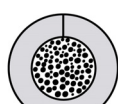
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Types of Cored Wire



Seamless cored wire



Butt joint cored wire



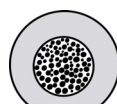
Overlapping cored wire

- Not sensitive to moisture pick-up.
- Can be copper coated - better current transfer.
- Thick sheath - good form stability - 2 roll drive feeding possible.
- Difficult to manufacture.

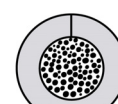
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Types of Cored Wire



Seamless cored wire



Butt joint cored wire



Overlapping cored wire

- Good resistance to moisture pick-up.
- Can be copper coated.
- Thick sheath.
- Difficult to seal the sheath.

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Types of Cored Wire

Seamless cored wire Butt joint cored wire Overlapping cored wire

- Sensitive to moisture pick-up.
- Cannot be copper coated.
- Thin sheath.
- Easy to manufacture.

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Welding Consumables

SAW Consumables

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SAW Filler Material

Welding wires

- Supplied on coils, reels or drums.
- Random or line winding.

Courtesy of Lincoln Electric Courtesy of Lincoln Electric Courtesy of ESAB AB

Coil (approximately 25kg) **Reel** (approximately 300kg) **Drum** (approximately 450kg)

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SAW Filler Material

Welding wires can be used to weld

- Carbon steels.
- Low alloy steels.
- Creep resisting steels.
- Stainless steels.
- Nickel-base alloys.
- Special alloys for surfacing applications.

Welding wires can be

- Solid wires.
- Metal-cored wires.

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SAW Filler Material

Welding wires

- Carbon and low alloy wires are copper coated.
- Stainless steel wires are not coated.

Courtesy of Lincoln Electric Courtesy of Lincoln Electric

- Wires must be kept clean and free from oil and dust.

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SAW Filler Material

Copper coating functions

- To assure a good electric contact between wire and contact tip.
- To assure a smooth feed of the wire through the guide tube, feed rolls and contact tip (decrease contact tube wear).
- To provide protection against corrosion.

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SAW Consumables

Welding fluxes

- Are granular mineral compounds mixed according to various formulations.
- Shield the molten weld pool from the atmosphere.
- Clean the molten weld pool.
- Can modify the chemical composition of the weld metal.
- Prevents rapid escape of heat from welding zone.
- Influence the shape of the weld bead (wetting action).
- Can be fused, agglomerated or mixed.
- Must be kept warm and dry to avoid porosity.

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SAW Consumables

Welding flux

- Supplied in bags/pails (approximately 25kg) or bulk bags (approximately 1200kg).
- Might be fused, agglomerated or mixed.



Courtesy of Lincoln Electric



Courtesy of Lincoln Electric



Courtesy of Lincoln Electric

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SAW Consumables

SA welding flux:

- Must be kept warm and dry.
- Handling and stacking requires care.

Fused fluxes:

- Are normally not hygroscopic but particles can hold surface moisture.
- Only drying.

Agglomerated fluxes:

- Contain chemically bonded water.
- Similar treatment as basic electrodes.
- For high quality, agglomerated fluxes can be recycled with new flux added.
- If flux is too fine it will pack and not feed properly.
- Cannot be recycled indefinitely.

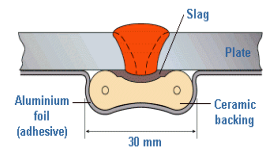
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Ceramic Backing

Ceramic backing

- Used to support the weld pool on root runs.
- Usually fitted on an aluminium self adhesive tape.
- Allow increased welding current without danger of burn-through - increased productivity, consistent quality.
- Different profiles to suit different applications.
- No backing/drying required.



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CSWIP 3.2 Senior Welding Inspector

Welding Consumables Inspection and Validation

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Inspection of Consumables

Why?

- To assess whether the products are in compliance with the requirements of the order or not - see BS EN 10204.

How?

- Non-specific inspection:
 - Carried out by the manufacturer in accordance with its own procedures.
 - The products inspected are **not** necessarily the products supplied!

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Inspection of Consumables

Specific inspection

- Carried out before delivery in accordance to product specification.
- Inspection is performed on the products to be supplied or on test units of which the products supplied are part.

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BS EN 10204-Type of Documents

```

graph TD
    A[Non-specific inspection documents] --> B[Type 2.1]
    A --> C[Type 2.2]
  
```

Type 2.1	Type 2.2
- Name: - Declaration of compliance with the order. - Content: - Statement of compliance with the order (doesn't include test results!) - Who validate it: - The manufacturer.	- Name: - Test report. - Content: - Statement of compliance with the order (include test results!) - Who validate it: - The manufacturer.

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BS EN 10204-Type of Documents

```

graph TD
    A[Specific inspection documents] --> B[Type 3.1]
    A --> C[Type 3.2]
  
```

Type 3.1	Type 3.2
- Name: - Inspection certificate 3.1. - Content: - Statement of compliance with the order (include specific test results!) - Who validate it? - The manufacturer inspection (independent of manufacturing department!)	- Name: - Inspection certificate 3.2. - Content: - Statement of compliance with the order (include specific test results!) - Who validate it? - The manufacturer inspection (independent of manufacturing department!) + purchaser's/ official designated authorised inspector.

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Welding Consumables

Any Questions

?

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Welding Consumables

You are currently employed as a Senior Welding Inspector in a fabrication yard.

The yard has numerous major oil and gas projects under construction.

Part of your duties is to monitor the control, storage and handling of welding consumables used during the construction.

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Question 1

One of your inspectors informs you that a batch of E8018 electrodes has arrived on site and requires a heat treatment before use. Which of the following best applies to this type of electrode?

- Generally this type of electrode can be used directly from the container with no heat treatments required
- In accordance with the TWI Specification, these types of electrodes are not permitted for use on this type of fabrication
- This type of electrode can be used providing the electrodes flux has been recycled to a maximum of 50:50 ratios old to new
- All options are incorrect

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Question 2

During welding one of your inspectors informs you that the fabricators are recycling SAW welding flux 30% new to 70% old. Is this permitted in accordance with the TWI Specification?

- a. This would not be permitted as the TWI specification states a ratio of 50:50 shall be applied
- b. SAW fluxes can't be recycled under any conditions
- c. This would be permitted as it's in accordance with the TWI Specifications
- d. This decision would generally be up to the welding supervisor

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Question 3

You are informed that the approved supplier of electrodes cannot make a delivery for two weeks. He asks if another manufacturer can be used, the electrodes are the same specification and size.

- a. No, the electrodes must be from the original manufacturer (Table 7)
- b. Yes, the electrodes can be used as they are the same specification.
- c. It depends on whether the client will accept the change
- d. They can be accepted once an all weld tensile test is completed.

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Question 4

A large batch of MAG wires has arrived on site, one of your inspectors informs you that the copper coating on some of the wire spools has been damaged during transportation. What is the purpose of the copper coating?

- a. The copper is added to the wire to aid fusion and improve mechanical properties of the deposited weld metal.
- b. The copper aides electrical pick up and protects the wire from corrosion
- c. The copper coating promotes weld metal fluidity and improves positional welding
- d. All options are incorrect

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Question 5

A batch of E46 3 1Ni B electrodes has arrived on site. One of your inspectors asks the question "what is the minimum yield value of these electrodes". Which of the following is correct?

- a. In accordance with AWS A5.1 the minimum UTS value would be 460 N/mm²
- b. In accordance with BS EN ISO 2560 the minimum UTS value would be 720 N/mm²
- c. In accordance with BS EN ISO 2560 the minimum yield value would be 460 N/mm²
- d. In accordance with BS EN ISO 2560 the minimum yield value would be 500 N/mm²

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Question 6

You notice a batch of cellulosic electrodes in the welding consumable store, which of the following statements is correct for this type of electrode?

- a. These electrodes can be used to control hydrogen levels to below 15ml per 100 grams of weld metal
- b. These electrodes should be baked prior to use
- c. These type of electrodes are especially suited to the PG welding position
- d. 2 Options are correct

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Question 7

During your morning inspection of the welding stores, you notice that certain electrodes are being baked in their original container in correctly controlled baking ovens. In accordance with the TWI Specification is this a correct practice?

- a. Yes, providing the treatment is in accordance with the manufacturers instructions
- b. No, under no circumstances should electrodes be baked
- c. Yes providing after baking the electrodes are stored in such a way as to keep them free from moisture intake
- d. No, not permitted

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Question 8

A Q&T section is being welded with rutile electrodes. It has been proved that Hydrogen cracking does not occur in this type of parent material. Which of the following statements are true?

- a. If HICC is not a problem in the parent material, rutile electrodes can be used.
- b. Basic electrodes must be used as the cracking occurs in the weld metal
- c. If the rutile electrodes are baked before use, the hydrogen level should not be a problem
- d. Any process that produces less than 20ml of hydrogen per 100 grams of weld metal should stop any HICC occurring.

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Question 9

One of your inspectors is unsure of the toughness value of an electrode classified as E50 3 2Ni B, which of the following is the correct answer?

- a. Maximum toughness 47J at -30°C
- b. Minimum toughness 50J at -20°C
- c. Minimum toughness 47J at -30°C
- d. Maximum toughness 50J at -20°C

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Question 10

Tungsten electrodes are considered consumables. Therefore, it is crucial that they are used correctly. Which of the following statements is correct concerning Tungsten electrodes?

- a. Zirconiated electrodes are used on DC negative as they concentrate the arc
- b. Zirconiated electrodes are used on AC as they can withstand more heat on the positive cycle
- c. Zirconiated electrodes are multi purpose for use on DC and AC
- d. Zirconiated electrodes are designed to be used with a long taper preparation.

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Section 16

MAG Welding

16 MAG Welding

16.1 The process

Known in the USA as gas metal arc welding (GMAW). The MIG/MAG welding process is a versatile technique suitable for both thin sheet and thick section components in most metallic materials.

In the process, an arc is struck between the end of a wire electrode and the workpiece, melting both to form a weld pool. The wire serves as the source of heat (via the arc at the wire tip) and filler metal for the joint.

The wire is fed through a copper contact tube (also called a contact tip) which conducts welding current into the wire. The weld pool is protected from the surrounding atmosphere by a shielding gas fed through a nozzle surrounding the wire.

Shielding gas selection depends on the material being welded and the application. The wire is fed from a reel by a motor drive and the welder or machine moves the welding gun or torch along the joint line.

The process offers high productivity and is economical because the consumable wire is continuously fed. A diagram of the process is shown in Figure 16.1.

The MIG/MAG process uses semiautomatic, mechanised, or automatic equipment. In semiautomatic welding, the wire feed rate and arc length are controlled automatically, but the travel speed and wire position are under manual control.

In mechanised welding, all parameters are under automatic control, but they can be varied manually during welding, eg steering of the welding head and adjustment of wire feed speed and arc voltage.

With automatic equipment, there is no manual intervention during welding. Figure 16.2 shows equipment required for the MIG/MAG process.

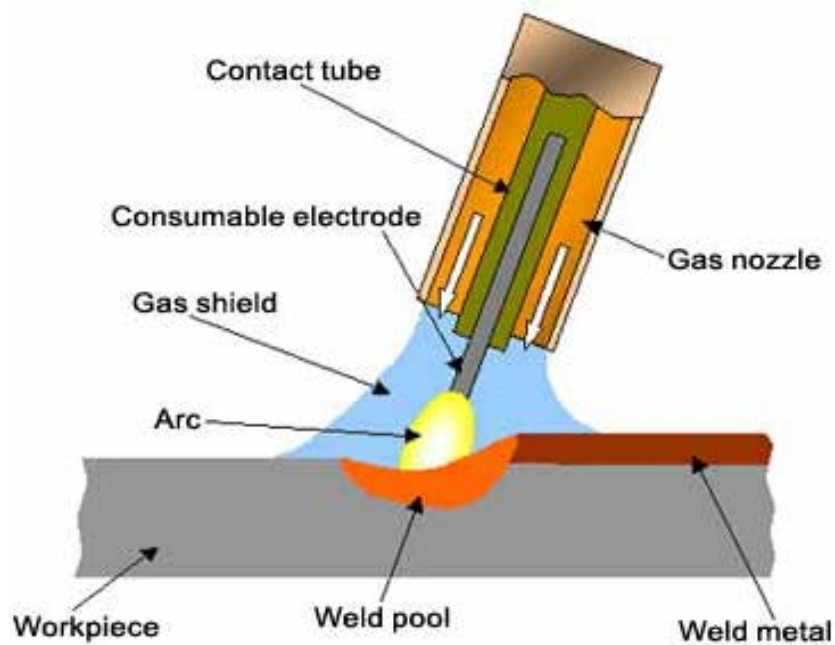


Figure 16.1 MIG/MAG welding.

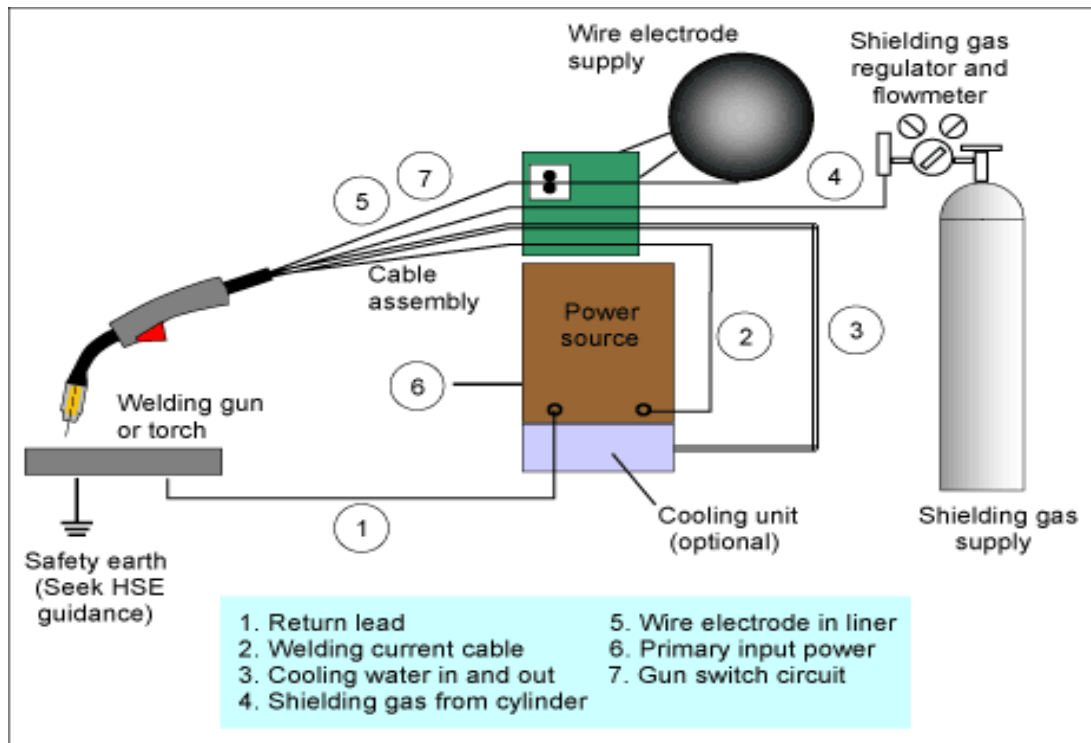


Figure 16.2 MIG/MAG welding equipment.

Advantages of the MIG/MAG process

- Continuous wire feed.
- Automatic self-regulation of the arc length.
- High deposition rate and minimal number of stop/start locations.
- High consumable efficiency.
- Heat inputs in the range 0.1-2.0kJ/mm.
- Low hydrogen potential process.
- Welder has good visibility of weld pool and joint line.
- Little or no post weld cleaning.
- Can be used in all positions (dip transfer).
- Good process control possibilities.
- Wide range of application.

Disadvantages

- No independent control of filler addition.
- Difficult to set up optimum parameters to minimise spatter levels.
- Risk of lack of fusion when using dip transfer on thicker weldments.
- High level of equipment maintenance.
- Lower heat input can lead to high hardness values.
- Higher equipment cost than MMA (manual metal arc) welding.
- Site welding requires special precautions to exclude draughts which may disturb the gas shield.
- Joint and part access is not as good as MMA or TIG welding.
- Cleanliness of base metal slag processes can tolerate greater contamination.

16.2 Process variables

The primary variables in MIG/MAG welding are:

- Welding current/wire feed speed.
- Voltage.
- Gases.
- Travel speed and electrode orientation.
- Inductance.
- Contact tip to work distance.
- Nozzle to work distance.
- Shielding gas nozzle.
- Type of metal transfer.

16.2.1 Welding current / wire feed speed

On MIG/MAG welding sets there is no control to set the welding current. The electrical characteristics of the welding set (flat or constant voltage type) automatically alters the welding current with changes to the set wire feed speed to achieve a constant arc length.

Increasing the wire feed, and therefore current, increases wire burn-off, deposition rate and penetration.

Current type is almost always DC+ve, although some cored wires require DC-ve for best results.

16.2.2 Voltage

This is set to achieve steady smooth welding conditions and is generally increased as the wire feed speed is increased.

Increase in voltage increases the width of the weld and reduces penetration.

16.2.3 Travel speed and electrode orientation

The faster the travel speed the less penetration, narrower bead width and the higher risk of undercut

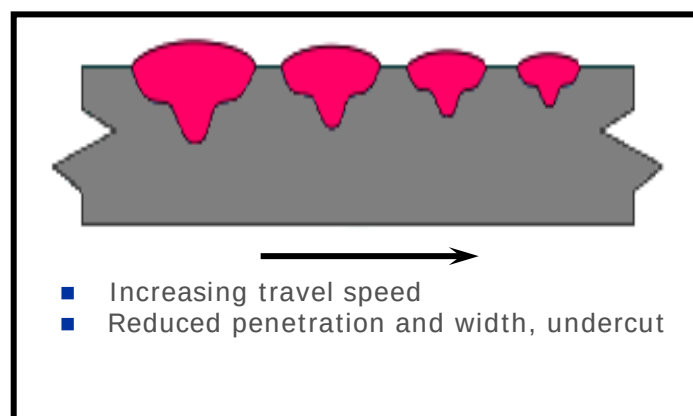


Figure 16.3 The effect of travel speed.

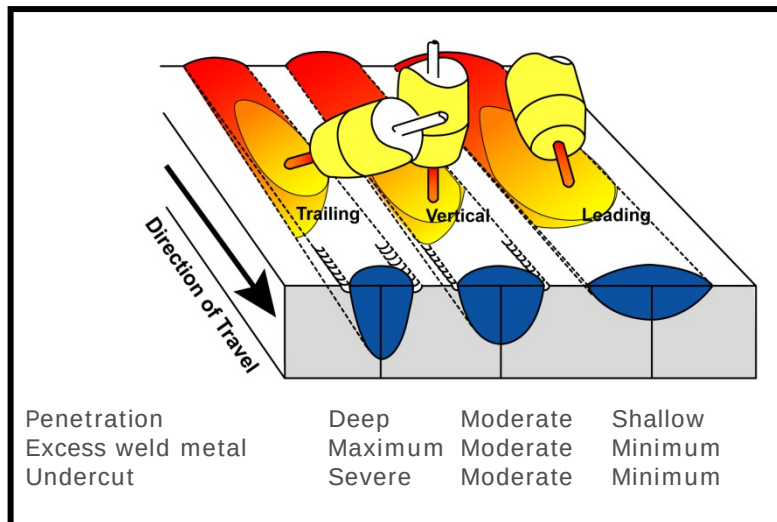


Figure 16.4 The effect of torch angle.

16.2.4 Effect of contact tip to workpiece distance (CTWD)

The CTWD has an influence over the welding current because of resistive heating in the electrode extension (see Figure 16.4). The welding current required to melt the electrode at the required rate (to match the wire feed speed) reduces as the CTWD is increased. Long electrode extensions can cause lack of penetration, for example, in narrow gap joints, or with poor manipulation of the welding gun. Conversely, the welding current increases when the CTWD is reduced.

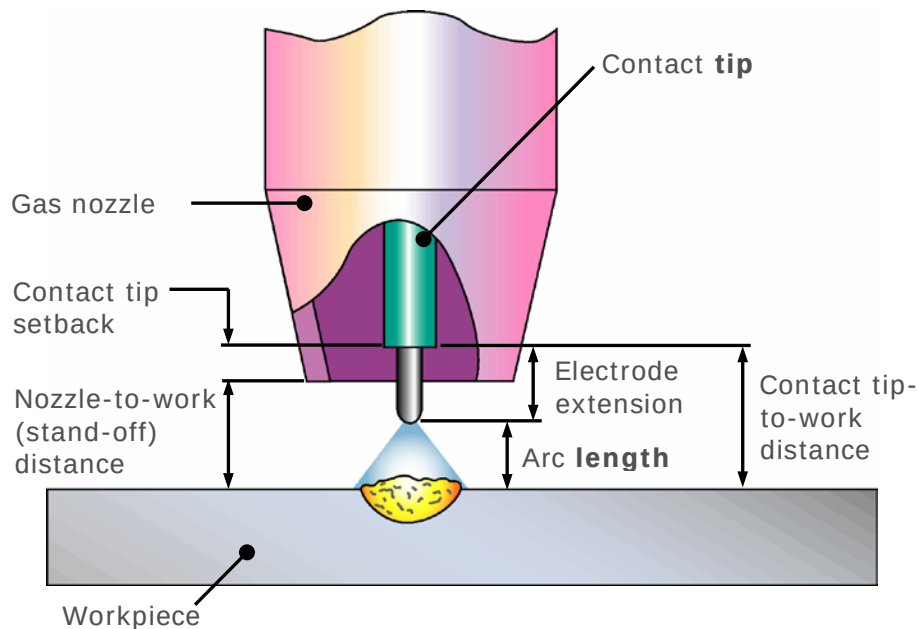


Figure 16.5 Contact tip to workpiece distance; electrode extension and nozzle to workpiece distance.

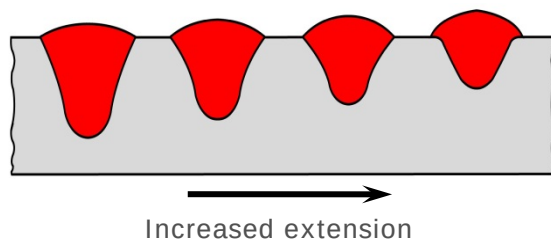


Figure 16.6 The effect of increasing electrode extension.

The electrode extension should be checked when setting-up welding conditions or when fitting a new contact tube. Normally measured from the contact tube to the work piece (Figure 16.5) suggested CTWDs for the principal metal transfer modes are:

Metal transfer mode	CTWD, mm
Dip	10-15
Spray	20-25
Pulse	15-20

16.2.5 Effect of nozzle to work distance

Nozzle to work distance (see Figure 16.4) has a considerable effect on gas shielding efficiency; a decrease having the effect of stiffening the column. The nozzle to work distance is typically 12-15mm. If the CTWD is simultaneously reduced, however, the deposition rate at a given current is decreased and visibility and accessibility are affected; so, in practice, a compromise is necessary. The following gives suggested settings for the mode of metal transfer being used

Metal transfer mode	Contact tip position relative to nozzle
Dip	2mm inside to 2mm protruding
Spray	4-8mm inside
Spray (aluminium)	6-10mm inside

16.2.6 Shielding gas nozzle

The purpose of the shielding gas nozzle is to produce a laminar gas flow in order to protect the weld pool from atmospheric contamination. Nozzle sizes range from 13-22mm diameter. The nozzle diameter should be increased in relation to the size of the weld pool.

16.2.7 Types of metal transfer

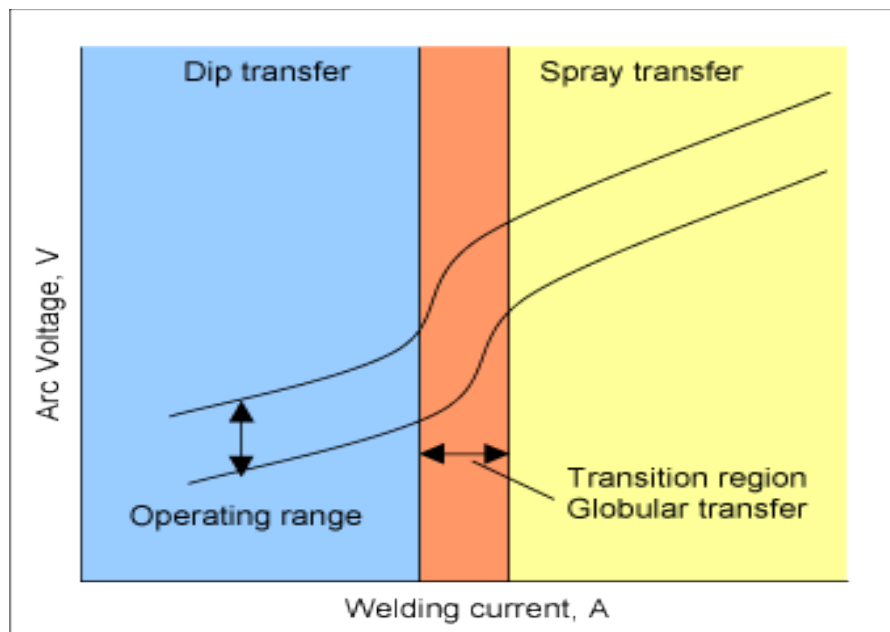


Figure 16.7 Arc characteristic curve.

1 Dip transfer:

Key characteristics:

- Metal transfer by wire dipping or short circuiting into the weld pool.
- Relatively low heat input process.
- Low weld pool fluidity.
- Used for thin sheet metal above 0.8 and typically less than 3.2mm, positional welding of thicker section and root runs in open butt joints.
- Process stability and spatter can be a problem if poorly tuned.
- Lack of fusion risk if poorly set up and applied.
- Not used for non-ferrous metals and alloys.

In dip transfer the wire short-circuits the arc between 50–200 times/sec. This type of transfer is normally achieved with CO₂ or mixtures of CO₂ and argon gas + low amps and welding volts < 24V.



Figure 16.8 Dip transfer.

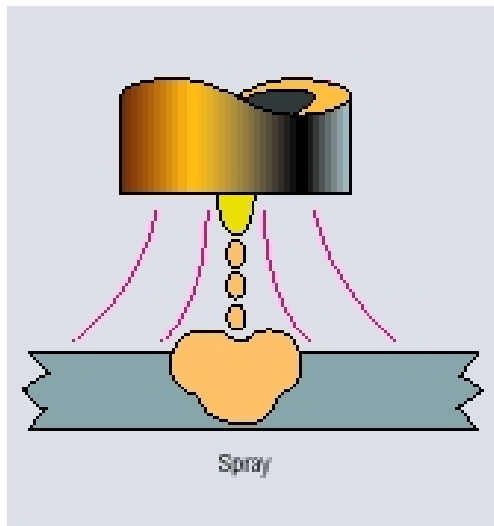
2 Spray transfer:

Key characteristics:

- Free-flight metal transfer.
- High heat input.
- High deposition rate.
- Smooth, stable arc.
- Used on steels above 6mm thickness and aluminium alloys above 3mm thickness.

Spray transfer occurs at high currents and high voltages. Above the transition current, metal transfer is in the form of a fine spray of small droplets, which are projected across the arc with low spatter levels. The high welding current produces strong electromagnetic forces (known as the pinch effect) that cause the molten filament supporting the droplet to neck down. The droplets detach from the tip of the wire and accelerate across the arc gap.

With steels it can be used only in down-hand butts and H/V fillet welds, but gives significantly higher deposition rate, penetration and fusion than the dip transfer mode. With aluminum alloys it can be used in all positions.



3 Pulsed transfer:

Key characteristics:

- Free-flight droplet transfer without short-circuiting over the entire working range.
- Very low spatter.
- Lower heat input than spray transfer.
- Reduced risk of lack of fusion compared with dip transfer.
- Control of weld bead profile for dynamically loaded parts.
- Process control/flexibility.
- Enables use of larger diameter, less expensive wires with thinner plates – more.
- Easily fed (a particular advantage for aluminium welding).

Pulsing the welding current extends the range of spray transfer operation well below the natural transition from dip to spray transfer. This allows smooth, spatter-free spray transfer to be obtained at mean currents below the transition level, eg 50-150A and at lower heat inputs.

A typical pulse waveform and the main pulse welding variables are shown in Figure 16.10. Pulse transfer uses pulses of current to fire a single globule of metal across the arc gap at a frequency between 50–300 pulses/sec. 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.

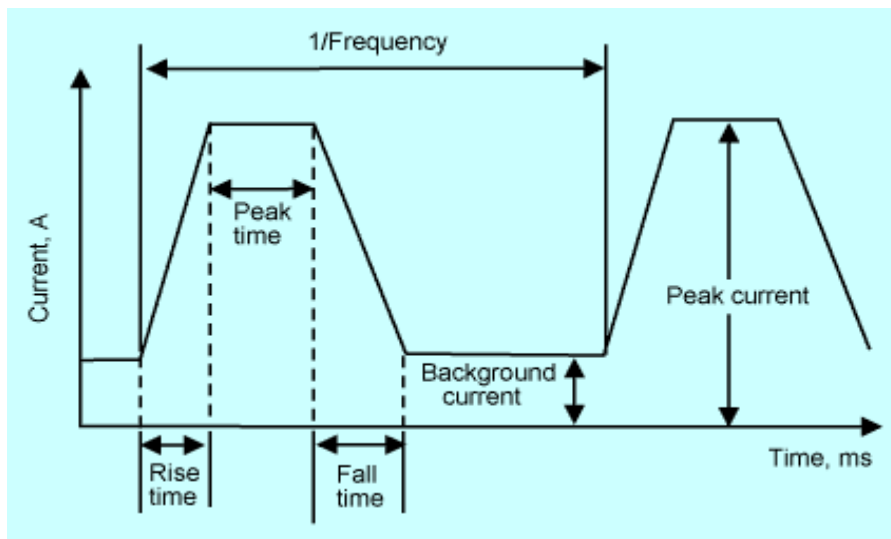


Figure 16.10 Pulsed welding waveform and parameters.

4 Globular transfer:

Key characteristics:

- Irregular metal transfer.
- Medium heat input.
- Medium deposition rate.
- Risk of spatter.
- Not widely used in the UK; can be used for mechanised welding of medium.
- Thickness steels (typically 3-6mm) in the flat (PA) position.

The globular transfer range occupies the transitional range of arc voltage between free flight and fully short-circuiting transfer. Irregular droplet transfer and arc instability are inherent, particularly when operating near the transition threshold. In globular transfer, a molten droplet of several times the electrode diameter forms on the wire tip. Gravity eventually detaches the globule when its weight overcomes surface tension forces and transfer takes place often with excessive spatter

To minimise spatter levels, it is common to operate with a very short arc length and in some cases a buried arc technique is adopted. Globular transfer can only be used in the flat position and is often associated with lack of penetration, fusion defects and uneven weld beads, because of the irregular transfer and tendency for arc wander.

16.2.8 Inductance

What does inductance do?

When MIG welding in the dip transfer mode, the welding electrode touches the weld pool, causing a short circuit. During the short circuit, the arc voltage is nearly zero. If the constant voltage power supply responded instantly, very high current would immediately begin to flow through the welding circuit. The rapid rise in current to a high value would melt the short-circuited electrode free with explosive force, dispelling the weld metal and causing considerable spatter.

Inductance is the property in an electrical circuit that slows down the rate of current rise (Figure 16.11). The current travelling through an inductance coil creates a magnetic field. This magnetic field creates a current in the welding circuit that is in opposition to the welding current. Increasing the inductance will also increase the arc time and decrease the frequency of short-circuiting.

For each electrode feed rate, there is an optimum value of inductance. Too little inductance results in excessive spatter. If too much inductance is used, the current will not rise fast enough and the molten tip of the electrode is not heated sufficiently causing the electrode to stub into the base metal. Modern electronic power sources automatically set the inductance to give a smooth arc and metal transfer.

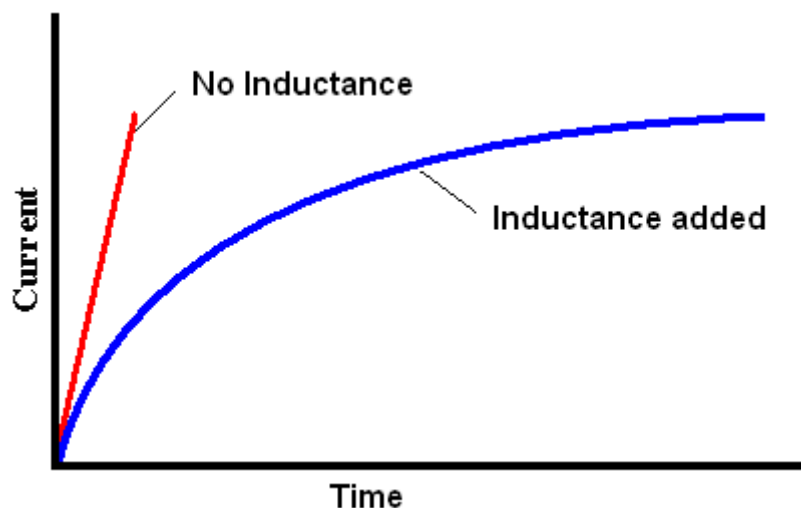


Figure 16.11 Relationship between inductance and current rise.

16.3 Welding consumables

16.3.1 Solid wires

Usually made in sizes from 0.6 to 1,6mm diameter they are produced with an analysis which essentially matches the materials being joined. Additional elements are often added especially extra de-oxidants in steel wires. C-Mn and low alloy steel wires are usually copper coated to reduce the risk of rusting and promote better electrical contact.

16.3.2 Flux cored wires

A cored wire consists of a metal sheath containing a granular flux. This flux can contain elements that would normally be used in MMA electrodes and so the process has a very wide range of applications.

In addition we can also add gas producing elements and compounds to the flux and so the process can become independent of a separate gas shield, which restricted the use of conventional MIG/MAG welding in many field applications.

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 as moisture can easily be absorbed into a damaged or poor seam.

Wire types commonly used are:

- Rutile – which give good positional capabilities..
- Basic – also positional but good on “dirty” material.
- Metal cored – higher productivity and some having excellent root run capabilities.
- Self-shielded – no external gas needed.

Baking of cored wires is ineffective and will do nothing to restore the condition of a contaminated flux within a wire.

Note: Unlike MMA electrodes the potential hydrogen levels and mechanical properties of welds with rutile wires can equal those of the basic types.

16.4 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 of the wire is an important factor with single, double and triple de-oxidised wires being available.

The higher the level of de-oxidants in the wire, then the lower the chance of porosity in the weld. The quality of the wire winding, copper coating, and temper are also important factors in minimising 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 ovular 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 liner is the correct type and size for the wire. A size of liner will generally fit 2 sizes of wire ie (0.6 and 0.8) (1.0 and 1.2) (1.4 and 1.6) mm diameter. Steel liners are used for steel wires and Teflon liners for aluminium wires.

4 The contact tip

Check that the contact tip is the correct size for the wire being driven, and 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, this also inhibits corrosion. The contact tip should be replaced 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 nature and stability of the electric arc, and is thus a major inspection point.

6 Gas and gas flow rate

The type of gas used is extremely important to 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 to avoid oxidation and porosity.

7 Other variable welding parameters

Checks should be made for correct wire feed speed, voltage, speed of travel, and 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** during dip transfer welding thick section vertically down.
- 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 metal.

Section 17

MMA Welding

17 MMA Welding

17.1 Manual metal arc/shielded metal arc welding (MMA/SMAW)

The most versatile of the welding processes, manual metal arc (MMA) welding is suitable for welding most ferrous and non-ferrous metals, over a wide range of thicknesses. The MMA welding process can be used in all positions, with reasonable ease of use and relatively economically. The final weld quality is primarily dependent on the skill of the welder.

When an arc is struck between the coated electrode and the workpiece, both the electrode and workpiece surface melt to form a weld pool. The average temperature of the arc is approximately 6000°C , which is sufficient to simultaneously melt the parent metal, consumable core wire and the flux coating. The flux forms gas and slag, which protects the weld pool from oxygen and nitrogen in the surrounding atmosphere. The molten slag solidifies and cools and must be chipped off the weld bead once the weld run is complete (or before the next weld pass is deposited). The process allows only short lengths of weld to be produced before a new electrode needs to be inserted in the holder.

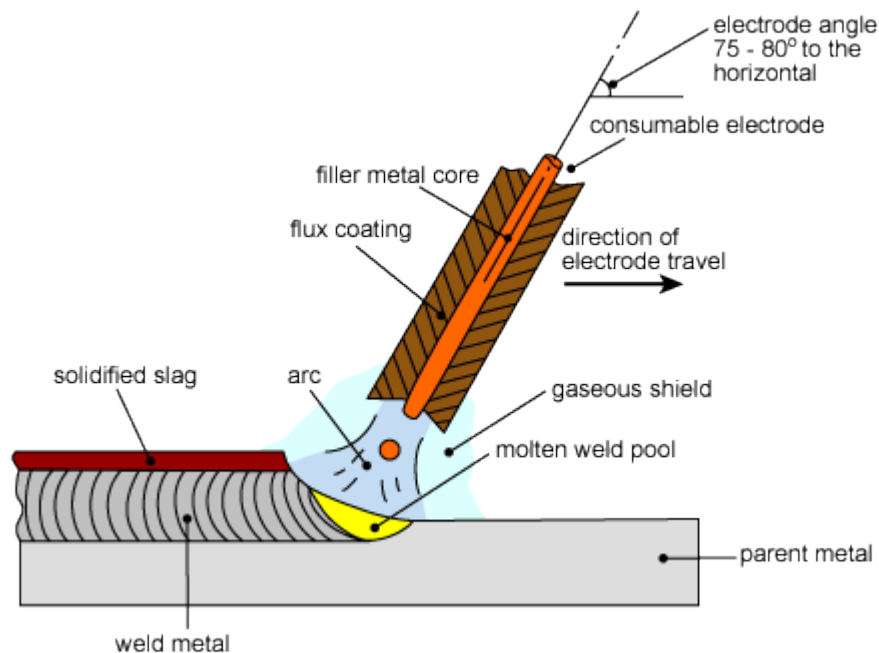


Figure 17.1 The manual metal arc welding process.

17.2 MMA welding basic equipment requirements



- 1 **Power source transformer/rectifier** (constant current type).
- 2 **Holding oven** (holds at temperatures up to 150°C).
- 3 **Inverter power source** (more compact and portable).
- 4 **Electrode holder** (of a suitable amperage rating).
- 5 **Power cable** (of a suitable amperage rating).
- 6 **Welding visor** (with correct rating for the amperage/process).
- 7 **Power return cable** (of a suitable amperage rating).
- 8 **Electrodes** (of a suitable type and amperage rating).
- 9 **Electrode oven** (bakes electrodes at up to 350°C).
- 10 **Control panel** (on/off/amperage/polarity/OCV).

Figure 17.2 MMA welding basic equipment.

17.3 Power requirements

Manual metal arc welding can be carried out using either direct (DC) or alternating (AC) current. With DC welding current either positive (+ve) or negative (-ve) polarity can be used, so current is flowing in one direction. AC welding current flows from negative to positive and is two directional.

Power sources for MMA welding are transformers (which transforms mains AC to AC suitable for welding), transformer-rectifiers (which rectifies AC to DC), diesel or petrol driven generators (preferred for site work) or inverters (a more recent addition to welding power sources). For MMA welding a power source with a constant current (drooping) output characteristic must be used.

The power source must provide:

- An open circuit voltage (OCV) to initiate the arc, between 50 and 90V.
- Welding voltage to maintain the arc during welding, between 20 and 30V.
- A suitable current range, typically 30-350A.
- A stable arc. Rapid arc recovery or arc re-ignition without current surge.
- A constant welding current. The arc length may change during welding, but consistent electrode burn-off rate and weld penetration characteristics must be maintained during welding.

17.4 Welding variables

Other factors, or welding variables, which affect the final quality of the MMA weld, are:

- Current (amperage)
 - Voltage.
 - Travel speed.
 - Polarity.
 - Type of electrode.
- } affects heat Input

17.4.1 Current (amperage)

Amperage controls burn-off rate and depth of penetration. Welding current level is determined by the size of electrode and the welding position - manufacturers recommend the normal operating range and current.

Incorrect amperage settings when using MMA can contribute to the following:

Amperage too low

Poor fusion or penetration, irregular weld bead shape, slag inclusion unstable arc, porosity, potential arc strikes, difficult starting.

Amperage too high

Excessive penetration, burn-through, undercut, spatter, porosity, deep craters, electrode damage due to overheating, high deposition making positional welding difficult.

17.5 Voltage

Open circuit voltage (OCV) is the voltage measured between the output terminals of the power source when no current is flowing through the welding circuit.

For safety reasons this should not exceed 100V and is usually between 50-90V.

Arc voltage is the voltage required to maintain the arc during welding and is usually between 20–30V. As arc voltage is a function of arc length the welder controls the arc length and therefore the arc voltage.

Arc voltage controls weld pool fluidity.

The effects of having the wrong arc voltage can be:

Arc Voltage too low

Poor penetration, electrode stubbing, lack of fusion defects, potential for arc strikes, slag inclusion, unstable arc condition, irregular weld bead shape.

Arc voltage too high

Excessive spatter, porosity, arc wander, irregular weld bead shape, slag inclusions, fluid weld pool making positional welding difficult.

17.5.1 Travel speed

Travel speed is related to whether the welding is progressed by stringer beads or by weaving. Often the run out length (ROL) ie the length of deposit from one standard electrode is quoted on procedures rather than speed as it is easier for the welder to visualise.

Travel speed too fast

Narrow thin weld bead, fast cooling, slag inclusions, undercut, poor fusion/penetration.

Travel speed too slow

Cold lap, excess weld deposition, irregular bead shape, undercut.

17.6 Type of current and polarity

Polarity will determine the distribution of heat energy at the welding arc. The preferred polarity of the MMA system depends primarily upon the electrode being used and the desired properties of the weld.

- **Direct current. electrode positive (DCEP / DC+).**
Usually produces the greatest penetration but with lesser deposition rate.
Known in some standards as reverse polarity.
- **Direct current. electrode negative (DCEN / DC-)**
Usually produces less penetration with greater deposition rate.
Known in some standards as straight polarity.

When using direct current the arc can be affected by *arc blow*. The deflection of the arc from its normal path due to magnetic forces.

- **Alternating current (AC)**
The distribution of heat energy at the arc is equal.
- **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 **O/F** 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 ie 350A 60% and 300A 100%.

17.7 Type of consumable electrode

For MMA welding there are three generic types of flux covering:

Rutile, basic, cellulosic

The details of these types are covered elsewhere in these notes.

17.8 Typical welding defects

- 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 the amps, root gap or face width.
- 4 **Undercut** caused by too high amperage for the position or by a poor welding technique eg 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.

Section 18

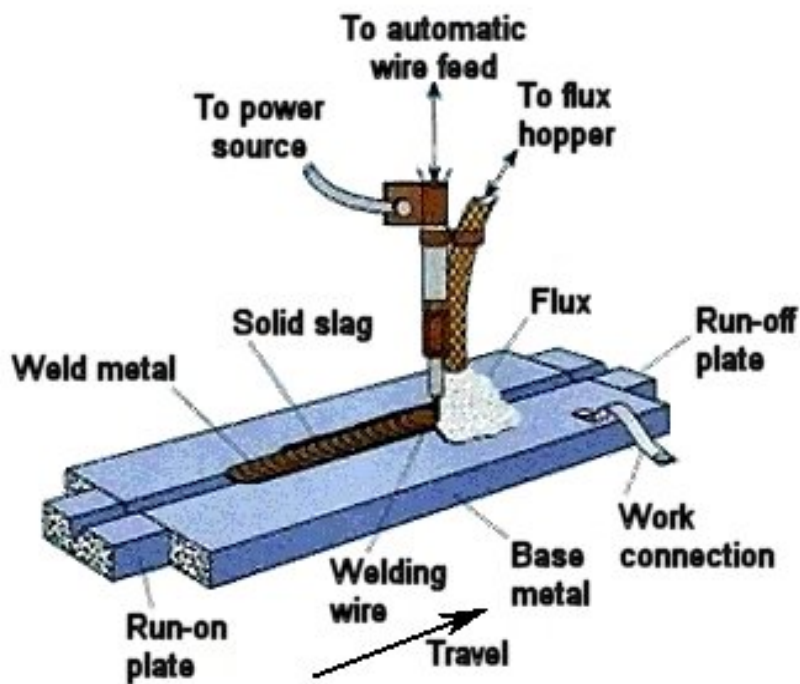
Submerged Arc Welding

18 Submerged Arc Welding

18.1 The process

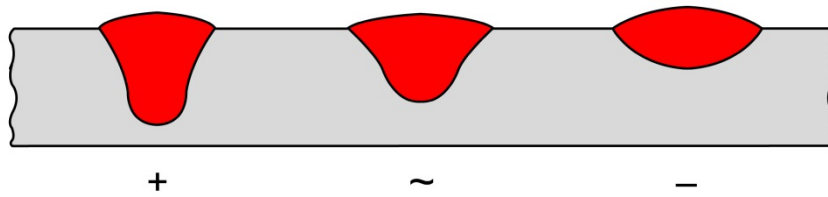
Abbreviated as SAW, this is a welding process where an arc is struck between a continuous bare wire and the parent plate. The arc, electrode end and the molten pool are submerged in an agglomerated or fused powdered flux, which turns, into gas and slag in its lower layers when subjected to the heat of the arc, thus protecting the weld from contamination.

The wire electrode is fed continuously by a feed unit of motor-driven rollers, which usually are voltage-controlled to ensure an arc of constant length. The flux is fed from a hopper fixed to the welding head, and a tube from the hopper spreads the flux in a continuous elongated mound in front of the arc along the line of the intended weld and of sufficient depth to submerge the arc completely so that there is no spatter, the weld is shielded from the atmosphere and there are no ultraviolet or infra-red radiation effects (see below). Unmelted flux is reclaimed for use. The use of powdered flux restricts the process to the flat and horizontal-vertical welding positions.



Submerged arc welding is noted for its ability to employ high weld currents owing to the properties and functions of the flux. Such currents give deep penetration and high deposition rates. Generally a DC electrode positive polarity is employed up to about 1000A because it produces a deep penetration. On some applications (ie cladding operations) DC electrode negative is needed to reduce penetration and dilution. At higher currents or in case of multiple electrode systems, AC is often preferred to avoid the problem of arc blow (when used with multiple electrode systems, DC electrode positive is used for the lead arc and **AC** is used for the trail arc).

Power sources can be of the constant current or constant voltage type either may have outputs exceeding 1000A.



Difficulties sometimes arise in ensuring conformity of the weld with a predetermined line owing to the obscuring effect of the flux. Where possible, a guide wheel or stylus to run in the joint preparation is positioned in front of the welding head and flux hoppers or alternatively a laser tracking system is used.

Submerged arc welding is widely used in the fabrication of ships, pressure vessels, linepipe, railway carriages and anywhere where long welds are required. It can be used to weld thicknesses from 1.5mm upwards.

Materials joined

- Welding of carbon steels.
- Welding low alloy steels (eg fine grained and creep resisting).
- Welding stainless steels.
- Welding nickel alloys.
- Cladding to base metals to improve wear and corrosion resistance.

18.2 Process variables

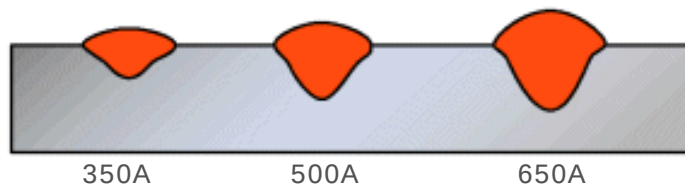
There are several variables which when changed can have an effect on the weld appearance and mechanical properties:

- Welding current.
- Type of flux and particle distribution.
- Arc voltage.
- Travel speed.
- Electrode size.
- Electrode extension.
- Type of electrode.
- Width and depth of the layer of flux.
- Electrode angle, (leading, trailing).
- Polarity.
- Single-, double- or multi-wire system.

18.2.1 Welding current

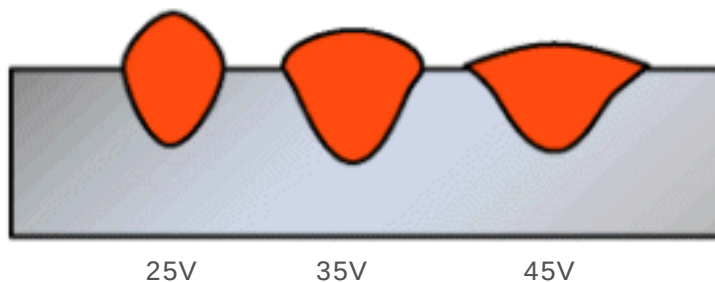
Welding current effect on weld profile (2.4mm electrode diameter, 35V arc voltage and 610mm/min travel speed)

- Excessively high current produces a deep penetrating arc with a tendency to burn-through, undercut or a high, narrow bead prone to solidification cracking.
- Excessively low current produces an unstable arc, lack of penetration and possibly lack of fusion.



18.2.2 Arc voltage

Arc voltage adjustment varies the length of the arc between the electrode and the molten weld metal. If the arc voltage increases, the arc length increases and vice versa. The voltage principally determines the shape of the weld bead cross section and its external appearance.



Arc voltage effect on weld profile (2.4mm electrode diameter, 500A welding current and 610mm/min travel speed).

Increasing the arc voltage will:

- Produce a flatter and wider bead.
- Increase flux consumption.
- Tend to reduce porosity caused by rust or scale on steel.
- Help to bridge excessive root opening when fit-up is poor.
- Increase pick-up of alloying elements from the flux when they are present.

Excessively high arc voltage will:

- Produce a wide bead shape that is subject to solidification cracking.
- Make slag removal difficult in groove welds.
- Produce a concave shaped fillet weld that may be subject to cracking.
- Increase undercut along the edge(s) of fillet welds.
- Over-alloy the weld metal, via the flux.

Reducing the arc voltage with constant current and travel speed will:

- Produce a stiffer arc which improves penetration in a deep weld groove and resists arc blow.

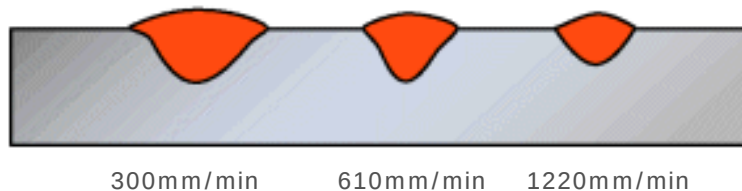
Excessively low arc voltage will:

- Produce a high, narrow bead.
- Causes difficult slag removal along the weld toes.

18.2.3 Travel speed

If the travel speed is increased:

- Heat input per unit length of weld is decreased.
- Less filler metal is applied per unit length of weld, and consequently less excess weld metal.
- Penetration decreases and thus the weld bead becomes smaller.

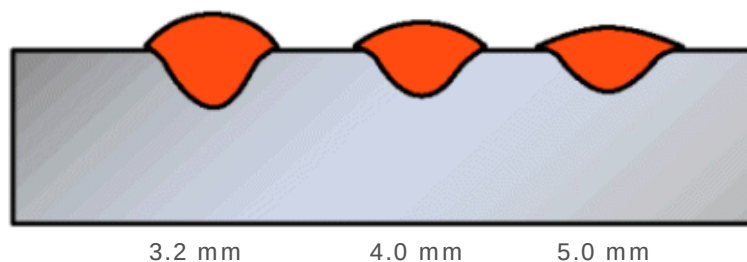


Travel speed effect on weld profile (2.4mm electrode diameter, 500A welding current and 35V arc voltage).

18.2.4 Electrode size

Electrode size affects:

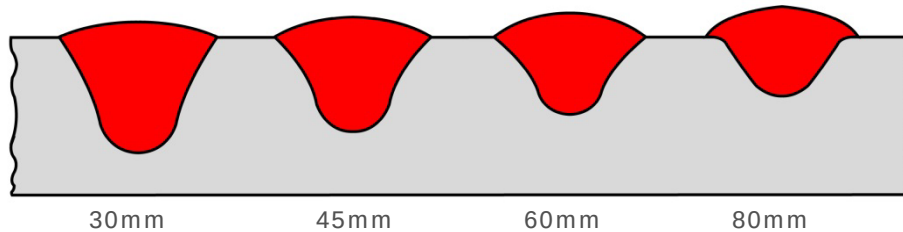
- The weld bead shape and the depth of penetration at a given current: a high current density results in a stiff arc that penetrates into the base metal. Conversely, a lower current density in the same size electrode results in a soft arc that is less penetrating.
- The deposition rate: at any given amperage setting, a small diameter electrode will have a higher current density and a higher deposition rate of molten metal than a larger diameter electrode. However, a larger diameter electrode can carry more current than a smaller electrode, so the larger electrode can ultimately produce a higher deposition rate at higher amperage.



Electrode size effect on weld profile (600A welding current, 30V arc voltage and 760mm/min travel speed).

18.2.5 Electrode extension

The electrode extension is the distance the continuous electrode protrudes beyond the contact tip. At high current densities, resistance heating of the electrode between the contact tip and the arc can be utilised to increase the electrode melting rate (as much as 25-50%). The longer the extension, the greater the amount of heating and the higher the melting rate (see below).



18.2.6 Type of electrode

An electrode with a low electrical conductivity, such as stainless steel, can with a normal electrode extension experience greater resistance heating. Thus for the same size electrode and current, the melting rate of a stainless steel electrode will be higher than that of a carbon steel electrode.

18.2.7 Width and depth of flux

The width and depth of the layer of granular flux influence the appearance and soundness of the finished weld as well as the welding action. If the granular layer is too deep, the arc is too confined and a rough weld with a rope-like appearance is likely to result, it may also produce local flat areas on the surface often referred to as gas flats. The gases generated during welding cannot readily escape, and the surface of the molten weld metal is irregularly distorted. If the granular layer is too shallow, the arc will not be entirely submerged in flux. Flashing and spattering will occur. The weld will have a poor appearance, and it may show porosity.

18.3 Storage and care of consumables

Care must be given to fluxes supplied for SAW which, although they may be dry when packaged, may be exposed to high humidity during storage. In such cases they should be stored in accordance with the manufacturer's recommendations before use, or porosity or cracking may result. It is rarely practical or economical to re-dry fluxes which may have picked up moisture.

Ferrous wire coils supplied as continuous feeding electrodes are usually copper-coated. This provides some corrosion resistance, ensures good electrical contacts and helps in smooth feeding. Rust and mechanical damage should be avoided in such products, as they will both interrupt smooth feeding of the electrode. Rust will be detrimental to weld quality generally since rust is a hygroscopic material (may contain or absorb moisture) and thus it can lead to hydrogen induced cracking.

Contamination by carbon containing materials such as oil, grease, paint and drawing lubricants is especially harmful with ferrous metals. Carbon pick-up in the weld metal can cause a marked and usually undesirable change in properties. Such contaminants may also result in hydrogen being absorbed in the weld pool.

Welders should always follow the manufacturer's recommendations for consumables storage and handling.

Section 19

TIG Welding

19 TIG Welding

19.1 Process characteristics

In the USA the TIG process is also called gas tungsten arc welding (GTAW). TIG welding is a process where melting is produced by heating with an arc struck between a non-consumable tungsten electrode and the workpiece.

An inert gas is used to shield the electrode and weld zone to prevent oxidation of the tungsten electrode and atmospheric contamination of the weld and hot filler wire (as shown below).

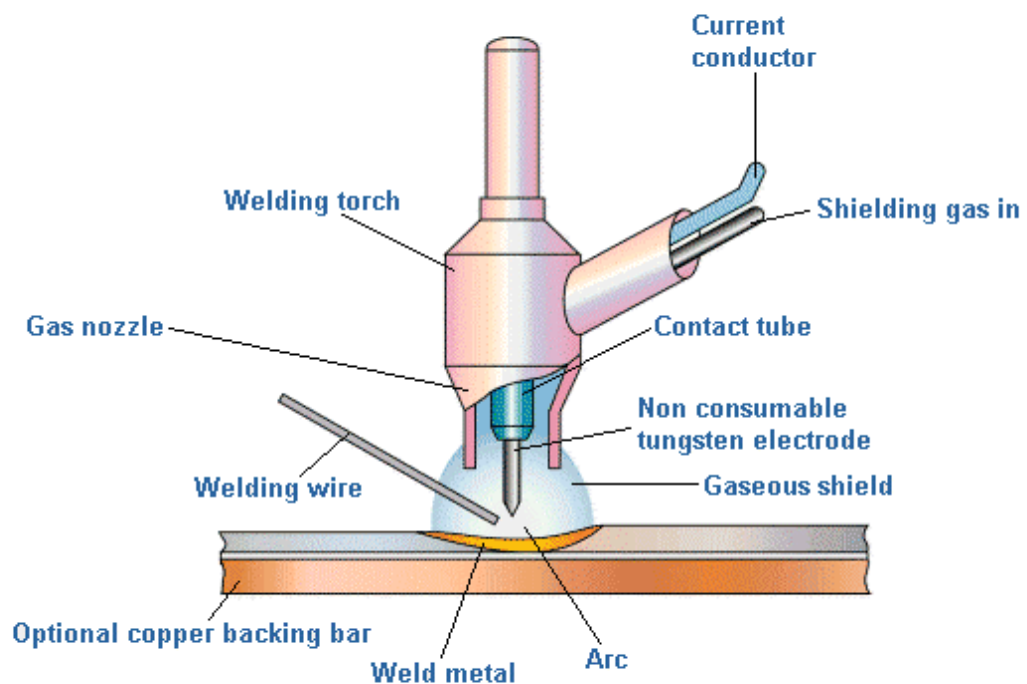


Figure 19.1 Manual TIG welding.

Tungsten is used because it has a melting point of 3370°C , which is well above any other common metal.

The power source is of the constant current type.

19.2 Process variables

The main variables in TIG welding are:

- Welding current.
- Current type and polarity.
- Travel speed.
- Shape of tungsten electrode tip and vertex angle.
- Shielding gas flow rate.

Each of these variables is considered in more detail in the following sub-sections.

19.2.1 Welding current

- Weld penetration is directly related to welding current.
- If the welding current is too low, the electrode tip will not be properly heated and an unstable arc may result.
- If the welding current is set too high, the electrode tip might overheat and melt, leading to tungsten inclusions.

19.2.2 Current type and polarity

- With steels DC electrode negative is used.
- Materials which have refractory oxides such as those of aluminium or magnesium are welded using AC or DC electrode positive which break up the oxide layer.
- With a DC positively connected electrode, heat is concentrated at the electrode tip and therefore for DC positive welding the electrode needs to be of greater diameter than when using DC negative if overheating of the tungsten is to be avoided. A water-cooled torch is recommended if DC positive is used.
- The current carrying capacity of a DC positive electrode is about one tenth that of a negative one and it is therefore limited to welding thin sections.

19.2.3 Travel speed

- Travel speed affects both weld width and penetration but the effect on width is more pronounced than on penetration.
- Increasing the travel speed reduces the penetration and width.
- Reducing the travel speed increases the penetration and width.

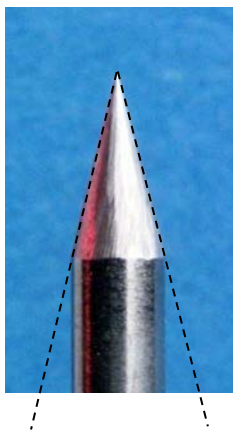
19.2.4 Tungsten electrode types

Different types of tungsten electrodes can be used to suit different applications:

- **Pure tungsten** electrodes are rarely used.
- **Thoriated electrodes** are alloyed with thorium oxide, typically 2%, to improve arc initiation. They have higher current carrying capacity than pure tungsten electrodes and maintain a sharp tip for longer. Unfortunately, thoria is slightly radioactive (emitting α radiation) and the dust generated during tip grinding should not be inhaled. Electrode grinding machines used for thoriated tungsten grinding should be fitted with a dust extraction system.
- **Ceriated and lanthanated electrodes** are alloyed with cerium and lanthanum oxides, for the same reason as thoriated electrodes. They operate successfully with DC or AC but since cerium and lanthanum are not radioactive, these types have been used as replacements for thoriated electrodes.
- **Zirconiated electrodes** are alloyed with zirconium oxide. Operating characteristics of these electrodes fall between the thoriated types and pure tungsten. However, since they are able to retain a balled end during welding, they are recommended for AC welding. Also, they have a high resistance to contamination and so they are used for high integrity welds where tungsten inclusions must be avoided.

19.2.5 Shape of tungsten electrode tip

- With DC electrode negative, thoriated, ceriated or lanthanated tungsten electrodes are used with the end is ground to a specific angle (the electrode tip angle or vertex angle – shown below).
- As a general rule, the length of the ground portion of the tip of the electrode should have a length equal to approximately 2-2.5 times the electrode diameter.
- The tip of the electrode is ground flat to minimise the risk of the tip breaking off when the arc is initiated or during welding (shown below).
- If the vertex angle is increased, the penetration increases.
- If the vertex angle is decreased, bead width increases.
- For AC welding, pure or zirconiated tungsten electrodes are used.
- These are used with a hemispherical ('balled') end (as shown below).
- In order to produce a balled end the electrode is grounded, an arc initiated and the current increased until it melts the tip of the electrode.



Electrode tip angle
(or vertex angle)



Electrode tip with
with flat end



Electrode tip with a
balled end

Figure 19.2 Examples of shapes of electrode tips.

19.3 Filler wires and shielding gases

These are selected on the basis of the materials being welded. See the relevant chapter in these notes.

19.4 Tungsten inclusions

Small fragments of tungsten that enter a weld will always show up on radiographs (because of the relatively high density of this metal) and for most applications will not be acceptable.

Thermal shock to the tungsten causing small fragments to enter the weld pool is a common cause of tungsten inclusions and is the reason why modern power sources have a current slope-up device to minimise this risk.

This device allows the current to rise to the set value over a short period and so the tungsten is heated more slowly and gently.

19.5 Crater cracking

Crater cracking is one form of solidification cracking and some filler metals can be sensitive to it.

Modern power sources have a current slope-out device so that at the end of a weld when the welder switches off the current it reduces gradually and the weld pool gets smaller and shallower.

This means that the weld pool has a more favourable shape when it finally solidifies and crater cracking can be avoided.

19.6 Common applications of the TIG process

These include autogenous welding of longitudinal seams, in thin walled pipes and tubes, in stainless steel and other alloys, on continuous forming mills.

Using filler wires, TIG is used for making high quality joints in heavier gauge pipe and tubing for the chemical, petroleum and power generating industries.

It is also in the aerospace industry for such items as airframes and rocket motor cases.

19.7 Advantages of the TIG process

- It produces superior quality welds, with very low levels of diffusible hydrogen and so there is less danger of cold cracking.
- It does not give weld spatter nor slag inclusions which makes it particularly suitable for applications that require a high degree of cleanliness (eg pipework for the food and drinks industry, semi-conductors manufacturing, etc).
- It can be used with filler metal and on thin sections without filler; it can produce welds at relatively high speed.
- It enables welding variables to be accurately controlled and is particularly good for controlling weld root penetration in all positions of welding.
- It can be used to weld almost all weldable metals, including dissimilar joints, but is not generally used for those with low melting points such as lead and tin. The method is especially useful in welding the reactive metals with very stable oxides such as aluminium, magnesium, titanium and zirconium.
- The heat source and filler metal additions are controlled independently and thus it is very good for joining thin base metals.

19.8 Disadvantages of the TIG process

- It gives low deposition rates compared with other arc welding processes.
- There is a need for higher dexterity and welder co-ordination than with MIG/MAG or MMA welding.
- It is less economical than MMA or MIG/MAG for sections thicker than ~10mm.
- It is difficult to fully shield the weld zone in draughty conditions and so may not be suitable for site/field welding.
- Tungsten inclusions can occur if the electrode is allowed to contact the weld pool.
- The process does not have any cleaning action and so has low tolerance for contaminants on filler or base metals.

Section 20

Welding Repairs

20 Weld Repairs

Weld repairs can be divided into two specific areas:

- 1 Production repairs.
- 2 In service repairs.

The reasons for making a repair are many and varied. Typically, they range from the removal of weld defects induced during manufacture to a quick and temporary running-repair to an item of production plant. In these terms, the subject of welding repairs is also wide and varied and often confused with maintenance and refurbishment where the work can be scheduled.

With planned maintenance and refurbishment, sufficient time can be allowed to enable the tasks to be completed without production pressures being applied. In contrast, repairs are usually unplanned and may result in shortcuts being taken to allow the production programme to continue. It is, therefore, advisable for a fabricator to have an established policy on repairs and to have repair methods and procedures in place.

The manually controlled welding processes are the easiest to use, particularly if it is a local repair or one to be carried out on-site. Probably the most frequently used of these processes is manual metal arc (MMA) as this is versatile, portable and readily applicable to many alloys because of the wide range of off-the-shelf consumables. Repairs almost always result in higher residual stresses and increased distortion compared with first time welds. With carbon-manganese and low/medium alloy steels, the application of preheat and post-weld heat treatments may be required.

There are a number of key factors that need to be considered before undertaking any repair.

The most important being a judgement as to whether it is financially worthwhile. Before this judgement can be made, the fabricator needs to answer the following questions:

- 1 Can structural integrity be achieved if the item is repaired?
- 2 Are there any alternatives to welding?
- 3 What caused the defect and is it likely to happen again?
- 4 How is the defect to be removed and what welding process is to be used?
- 5 Which non-destructive testing (NDT) is required to ensure complete removal of the defect?
- 6 Will the welding procedures require approval/re-approval?
- 7 What will be the effect of welding distortion and residual stress?
- 8 Will heat treatment be required?
- 9 What NDT is required and how can acceptability of the repair be demonstrated?
- 10 Will approval of the repair be required - if yes, how and by whom?

Although a weld repair may be a relatively straightforward activity, in many instances it can be quite complex and various engineering disciplines may need to be involved to ensure a successful outcome.

It is recommended that there be an ongoing analysis of the types of defect carried out by the Q/C department to discover the likely reason for their occurrence, (Material/process or skill related.)

In general terms, a welding repair involves:

- 1 A detailed assessment to find out the extremity of the defect. This may involve the use of a surface or sub-surface NDT methods.
- 2 Cleaning the repair area, (removal of paint grease etc).
- 3 Once established the excavation site must be clearly identified and marked out.
- 4 An excavation procedure may be required (method used ie grinding, arc-air gouging, preheat requirements etc).
- 5 NDT should be used to locate the defect and confirm its removal.
- 6 A welding repair procedure/method statement with the appropriate* welding process, consumable, technique, controlled heat input and interpass temperatures etc will need to be approved.
- 7 Use of approved welders.
- 8 Dressing the weld and final visual.
- 9 NDT procedure/technique prepared and carried out to ensure that the defect has been successfully removed and repaired.
- 10 Any post repair heat treatment requirements.
- 11 Final NDT procedure/technique prepared and carried out after heat treatment requirements.
- 12 Applying protective treatments (painting etc as required).

(*Appropriate' means suitable for the alloys being repaired and may not apply in specific situations)

20.1 Production repairs

Repairs are usually identified during production inspection and evaluation of the reports is usually carried out by the Welding Inspector, or NDT operator. Discontinuities in the welds are only classed as defects when they are outside the permitted range permitted by the applied code or standard.

Before the repair can commence, a number of elements need to be fulfilled.

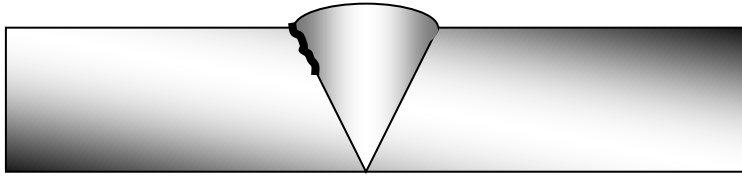
20.1.1 Analysis

As this defect is surface breaking and has occurred at the fusion face the problem could be cracking or lack of sidewall fusion. If the defect is found to be cracking the cause may be associated with the material or the welding procedure, however if the defect is lack of sidewall fusion this can be apportioned to the lack of skill of the welder.

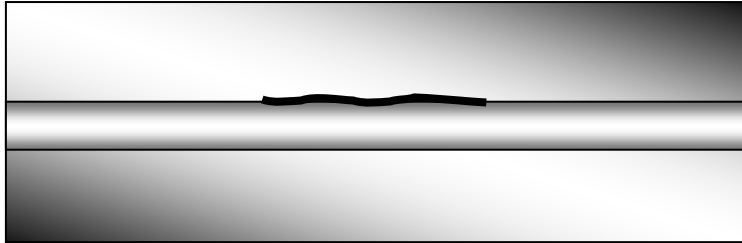
20.1.2 Assessment

In this particular case as the defect is open to the surface, magnetic particle inspection (MPI) or dye penetrant inspection (DPI) may be used to gauge the length of the defect and ultrasonic testing (U/T) used to gauge the depth.

A typical defect is shown below:



Plan view of defect



20.1.3 Excavation

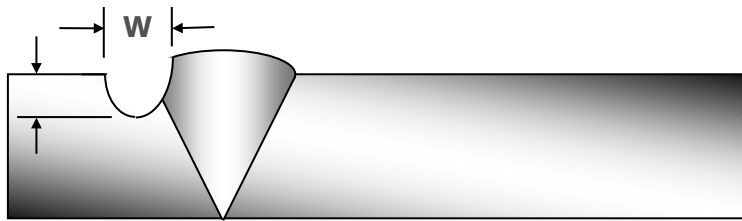
If a thermal method of excavation is being used ie arc-air gouging it may be a requirement to qualify a procedure as the heat generated may have an affect on the metallurgical structure, resulting in the risk of cracking in the weld or parent material



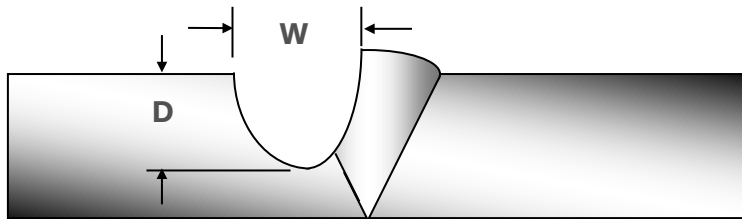
To prevent cracking it may be necessary to apply a preheat.

The depth to width ratio shall not be less than 1 (depth) to 1 (width) ideally 1 to 1.5 would be recommended (ratio: depth 1 to the width 1.5).

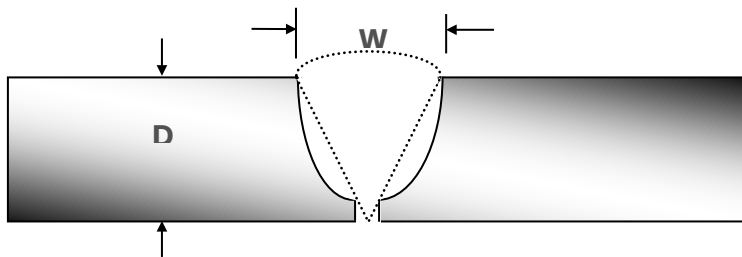
Side view of excavation for slight sub surface defect.



Side view of excavation for deep defect.



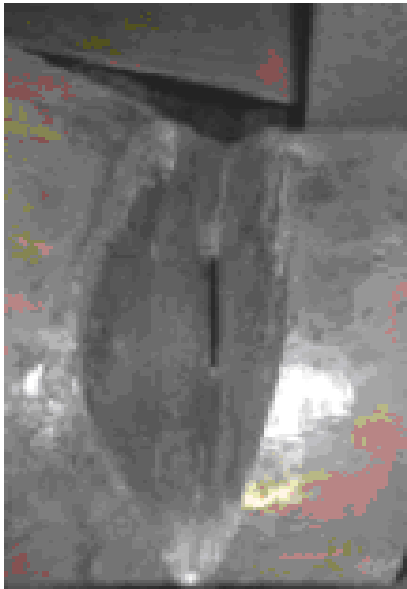
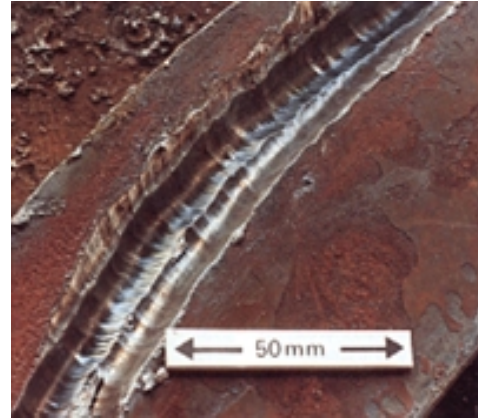
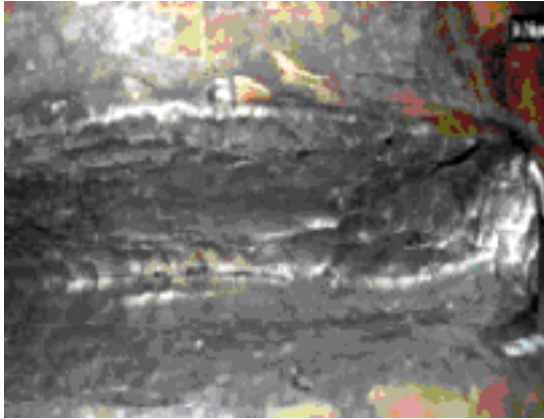
Side view of excavation for full root repair.



20.1.4 Cleaning of the excavation

At this stage grinding of the repair area is important, due to the risk of carbon becoming impregnated into the weld metal/parent material.

It should be ground back typically 3-4mm to bright metal.



Confirmation of excavation

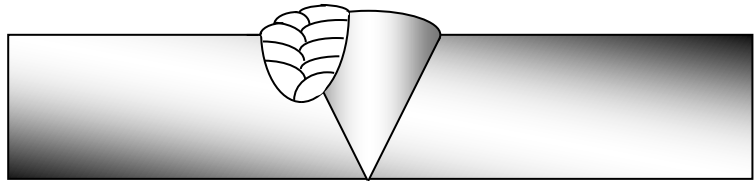
At this stage NDT should be used to confirm that the defect has been completely excavated from the area.

20.1.5 Re-welding of the excavation

Prior to re-welding of the excavation a detailed repair welding procedure/ method statement shall be approved.



Typical side view of weld repair



20.1.6 NDT confirmation of successful repair

After the excavation has been filled the weldment should then undergo a complete retest using the same NDT techniques as previously used to establish the original repair, this is carried out to ensure no further defects have been introduced by the repair welding process. NDT may also need to be further applied after any additional post-weld heat treatment has been carried out.

20.2 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 condition than it was 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 ie 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 bring other elements that need to be considered.

Repair of in service defects may require consideration of these and many other factors, and as such are generally considered more complicated than production repairs.

Joining technologies often play a vital role in the repair and maintenance of structures. Parts can be replaced, worn or corroded parts can be built up, and cracks can be repaired.

When a repair is required it is important to determine two things: firstly, the reason for failure and, secondly, can the component actually be repaired? The latter point infers that the material type is known. For metals, particularly those to be welded, the chemical composition is vitally important. Failure modes often indicate the approach required to make a sound repair. When the cause-effect analysis, however simple, is not followed through it is often the case that the repair is unsafe - sometimes disastrously so.

In many instances, the Standard or Code used to design the structure will define the type of repair that can be carried out and will also give guidance on the methods to be followed. Standards imply that when designing or manufacturing a new product it is important to consider a maintenance regime and repair procedures. Repairs may be required during manufacture and this situation should also be considered.

Normally, there is more than one way of making a repair. For example, cracks in cast iron might be held together or repaired by: pinning, bolting, riveting, welding, or brazing. The method chosen will depend on factors such as the reason for the failure, the material composition and cleanliness, the environment and the size and shape of the component.

It is **very important** that repair and maintenance welding are not regarded as activities, which are simple or straightforward. In many instances a repair may seem undemanding but the consequences of getting it wrong can be catastrophic failure with disastrous consequences.

Is welding the best method of repair?

If repair is called for because a component has a local irregularity or a shallow defect, grinding out any defects and blending to a smooth contour might well be acceptable. It will certainly be preferable if the steel has poor weldability or if fatigue loading is severe. It is often better to reduce the so-called factor of safety slightly, than to risk putting defects, stress concentrations and residual stresses into a brittle material.

In fact brittle materials - which can include some steels (particularly in thick sections) as well as cast irons - may not be able to withstand the residual stresses imposed by heavy weld repairs, particularly if defects are not all removed, leaving stress concentrations to initiate cracking.

Is the repair really like earlier repairs?

Repairs of one sort may have been routine for many years. It is important, however, to check that the next one is not subtly different. For example, the section thickness may be greater; the steel to be repaired may be different and less weldable, or the restraint higher. If there is any doubt, answer the remaining questions.

What is the composition and weldability of the base metal?

The original drawings will usually give some idea of the steel involved, although the specification limits may then have been less stringent, and the specification may not give enough compositional details to be helpful. If sulphur-bearing free-machining steel is involved, it could give hot cracking problems during welding.

If there is any doubt about the composition, a chemical analysis should be carried out. It is important to analyse for all elements, which may affect weldability (Ni, Cr, Mo, Cu, V, Nb and B) as well as those usually, specified (C, S, P, Si and Mn).

A small cost spent on analysis could prevent a valuable component being ruined by ill-prepared repairs or, save money by reducing or avoiding the need for preheat if the composition were leaner than expected. Once the composition is known, a welding procedure can be devised.

What strength is required from the repair?

The higher the yield strength of the repair weld metal, the greater will be the residual stress level on completion of welding, the greater the risk of cracking, the greater the clamping needed to avoid distortion and more difficulty in formulating the welding procedure. In any case, the practical limit for the yield strength of conventional steel weld metals is about 1000N/mm².

Can preheat be tolerated?

Not only does a high level of preheat make conditions more difficult for the welder; the parent steel can be damaged if it has been tempered at a low temperature. In other cases the steel being repaired may contain items, which are damaged by excessive heating. Preheat levels can be reduced by using consumables of ultra-low hydrogen content or by non-ferritic weld metals. Of these, austenitic electrodes may need some preheat, but the more expensive nickel alloys usually do not. However, the latter may be sensitive to high sulphur and phosphorus contents in the parent steel if diluted into the weld metal.

Can softening or hardening of the heat affected zone (HAZ) be tolerated?

Softening of the HAZ is likely in very high strength steels, particularly if they have been tempered at low temperatures. Such softening cannot be avoided, but its extent can be minimised. Hard HAZs are particularly vulnerable where service conditions can lead to stress corrosion. Solutions containing H₂S (hydrogen sulphide) may demand hardness' below 248HV (22HRC) although fresh aerated seawater appears to tolerate up to about 450HV. Excessively hard HAZ's may, therefore, require post-weld heat treatment (PWHT) to soften them but provided cracking has been avoided.

Is PWHT practicable?

Although it may be desirable, PWHT may not be possible for the same reasons that preheating is not possible. For large structures, local PWHT may be possible, but care should be taken to abide by the relevant codes, because it is all too easy to introduce new residual stresses by improperly executed PWHT.

Is PWHT necessary?

PWHT may be needed for one of several reasons, and the reason must be known before considering whether it can be avoided.

Will the fatigue resistance of the repair be adequate?

If the repair is in an area, which is highly stressed by fatigue, and particularly if the attempted repair is of a fatigue crack, inferior fatigue life can be expected unless the weld surface is ground smooth and no surface defects are left. Fillet welds, in which the root cannot be ground smooth, are not tolerable in areas of high fatigue stress.

Will the repair resist its environment?

Besides corrosion, it is important to consider the possibility of stress corrosion, corrosion fatigue, thermal fatigue and oxidation in service.

Corrosion and oxidation resistance usually requires that the composition of the filler metal is at least as noble or oxidation resistant as the parent metal. For corrosion fatigue resistance, the repair weld profile may need to be smoothed.

To resist stress corrosion, PWHT may be necessary to restore the correct microstructure, reduce hardness and reduce the residual stress left by the repair.

Can the repair be inspected and tested?

For onerous service, radiography and/or ultrasonic examination are often desirable, but problems are likely if stainless steel or nickel alloy filler is used; moreover, such repairs cannot be assessed by magnetic particle inspection. In such cases, it is particularly important to carry out the procedural tests for repairs very critically, to ensure that there are no risks of cracking and no likelihood of serious welder-induced defects.

Indeed, for all repair welds, it is vital to ensure that the welders are properly motivated and carefully supervised.

As-welded repairs

Repair without PWHT is, of course, normal where the original weld was not heat treated, but some alloy steels and many thick-sectioned components require PWHT to maintain a reasonable level of toughness, corrosion resistance etc. However, PWHT of components in service is not always easy or even possible, and local PWHT may give rise to more problems than it solves except in simple structures.

TWI

Weld Repairs

Section 20

Materials Joining and Engineering Technologies
Training and Examination Services

TWI

Repair Considerations

- The first thing to consider, is it worth repairing?
- Repair welding can cost up to ten times the original cost of making the weld, that's if it all goes according to plan.
- There could be access issues, contamination issues if it's in service.
- There could be metallurgical issues, changing properties etc.
- It may be more cost efficient to replace the component or cut the weld out completely.
- Try and establish the reason for defect occurrence as this may determine a change to the procedure or re training.
- Was the defect due to poor fit up conditions, misalignment.

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Cost of Weld Repairs

Original weld	Cost	Repair weld	Extra cost
Cut, prep, tack	£	Inspector Repair report (NCR etc)	££
Welder time	£	Inspector Identify repair area	££
Consumable & gas	£	Inspector Mark out repair area	££
Visual inspection	£	Welder Remove defect	££
NDT	££	Inspector Visual inspection of excavation	££
Documentation	£	Inspector NDT area of excavation	££
		Inspector Monitor repair welding	££
		Welder time	£
		Consumable & gas	£
		Inspector Visual inspection	££
		NDT	££
		Extra repair Documentation	£
		Penalty % NDT	££

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Repair Considerations

- Can pre heat be tolerated.
- Local pre heat and welding could lead to distortion and residual stress.
- In service repairs more complex, electrical and combustible material issues, contamination.
- Production repairs less complex.
- Approved repair procedure and welder.
- Mark accurately where material must be removed.

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Investigation

What is the nature of the defect?

- If the defect can be attributed to workmanship, it may not require further investigation.
- However, if it is some form of cracking, it will require further investigation as the problem may be repeated during the repair.

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Investigation

How was the defect detected?

- Visual.
- Dye Penetrant.
- Magnetic particle.
- Radiography.
- Ultrasonics.
- These processes are not always 100% accurate.
- Human error etc.

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Where is the Defect?

- Defects found on the surface by a NDT method that is surface only, may require further investigation using sub surface NDT.
- Remove defect and investigate further.
- Internal defects will be found with UT or X-Ray.
- UT, will be able to size and locate defect far better than X-Ray.

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What is the Defect?

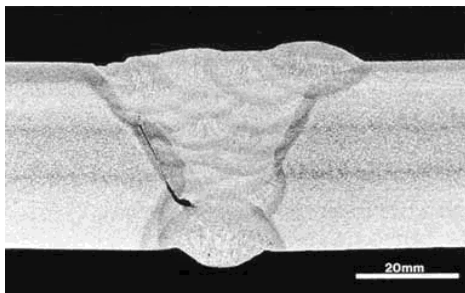
The process can help determine defect?

- A sub surface NDT method can help establish defect type with good interpretation.
- Porosity tends to be central in the weld and at restarts and finishes.
- Slag inclusions and lack of fusion defects tend to be between runs and at the side walls of the original preparation.

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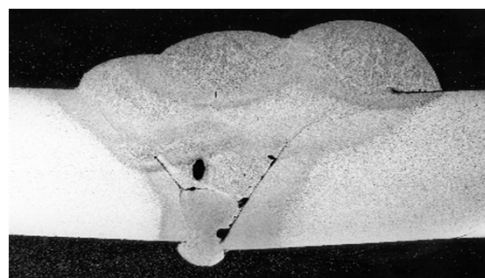
What is the Defect?



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What is the Defect?



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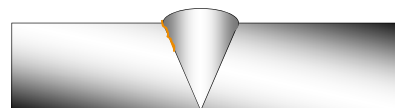
Removing Material

- Depending on the material, gouging, machining, filing, grinding can be used, pencil type de burrs for more intricate work.
- A greater area than just the defect area will have to be removed to allow for access and promote good fusion characteristics.
- If the depth of defect is not known, progressively remove material and NDT. check.

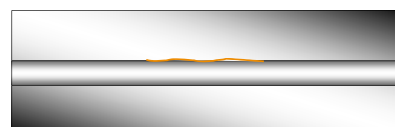
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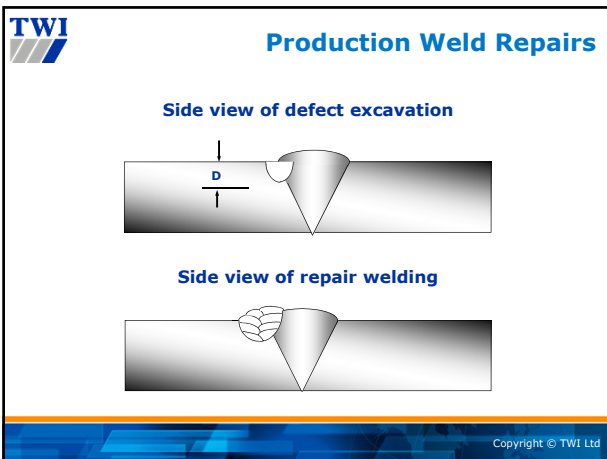
Weld Repairs



Plan View of defect



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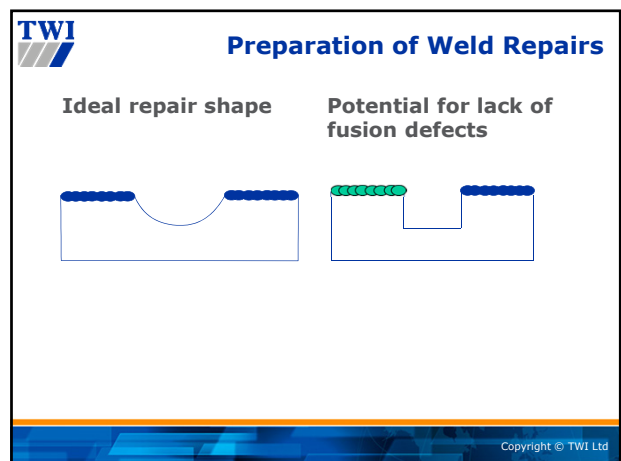


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Preparation of Weld Repairs

- The shape of the repaired area is very important.
- A boat type shape with large radius is preferred to allow good access and prevent any lack of fusion defects which could occur with straight edges.

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Considerations Before Welding

- Pre heat, ref original procedure.
- Distortion control measures, this could be quite dramatic as the heat concentration will generally be very localised.
- Materials such as S/S may require back purging; pipes etc.
- Process to use, TIG is probably the most versatile but there may be consumable match issues.

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Upon Completion

- PWHT to remove residual stress and/or hydrogen release.
- The repair may need dressing to give it the same geometry as the rest of the weld.
- Inspection of finished repair including NDT as original process used.
- Pressure testing if required.

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Repairs

You are working as a Senior Welding Inspector on a high pressure gas supply pipe line.

The pipe has a wall thickness of 12mm and in certain areas 25mm. The pipe is a 24" longitudinal seamed X60 grade, welded with the SAW process.

All circumferential seams are welded with an E6010 electrode for the root and hot pass, fillers and capping E8010 electrode, all passes in the PF position.

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Question 1

One of the circumferential seams has a linear slag inclusion 450mm in length and has been detected by radiography. Can this defect be repaired in accordance with the TWI Specification?

- a. This defect can be repaired providing the welding is conducted in the same direction as the original welding and under constant supervision
- b. Any defect exceeding 450mm in length cant be repaired in accordance with the TWI Specification
- c. This defect can be welded in accordance with the TWI specification, but must be welded using a basic type electrode and under constant supervision
- d. All options are incorrect

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Question 2

While witnessing a weld repair on a circumferential welded joint, the fabricator uses a preheat of 200°C. Would this pre heat temperature be correct in accordance with the TWI Specification?

- a. No, only 75°C preheats shall be used
- b. Yes providing the original preheat applied to the circumferential joint was 200°C
- c. Yes, providing the original preheat applied to the circumferential joint was 125°C
- d. No, preheats aren't permitted for repair welds on the circumferential seams

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Question 3

One of your welding inspectors reports back to you that a weld repair has been removed using the arc air gouging process. Is this acceptable in accordance with the TWI Specification?

- a. No, defective areas shall be removed by thermal cutting, grinding back to clean metal and inspected by MPI before commencement of welding
- b. Yes, providing the gouged area is cleaned by grinding back to clean metal, inspected by PT before commencement of welding
- c. Yes, providing the gouged area is cleaned by grinding back to clean metal, then visual inspection before the commencement of welding
- d. All options are incorrect

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Question 4

You notice that no weld repair procedures have been approved for this pipeline. In this situation would you permit any repairs to be conducted?

- a. Yes, providing all weld repairs are conducted in accordance with the TWI Specification
- b. Yes, providing that all welders are qualified to conduct the repairs
- c. No, all repair welding shall have an approved welding repair procedure
- d. No, repairs aren't generally conducted on pipelines; any defects detected would normally require the entire weld to be removed

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Question 5

One of your inspectors reports back to you that a crack has been repaired in Weld 42, section 34. Which of the following statements are correct?

- a. This would not be permitted, as cracks can't be repaired in accordance with the TWI Specification
- b. This would be permitted providing the crack didn't exceed the maximum repairable defect length
- c. This would be permitted providing the repair has been carried out in accordance with the approved repair WPS
- d. A crack like defect can't occur using the electrodes stated

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Question 6

After conducting a repair a slag inclusion that exceeds the maximum permitted length has been detected by radiography. The fabricator requests approval from you to conduct a weld repair in this defective area. Would you permit this repair?

- a. Yes, a repair can be conducted on this type of defect in accordance with the TWI Specification
- b. No, weld repairs are not permitted in accordance with the TWI Specification
- c. The TWI Specification makes no reference to this situation; you would need to ask advice on this situation
- d. No, in this situation the entire weld would have to be removed, a cutout

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Question 7

One of your welding inspectors informs you that a weld repair has been conducted without a qualified welding inspector present. In this situation which of the following applies?

- a. This is not permitted by the TWI Specification
- b. Providing the welder is qualified this is acceptable in accordance with the TWI Specification
- c. Providing the welder informs you that the approved repair WPS has been strictly adhered to this is acceptable
- d. No options are correct

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Question 8

You suspect that lack of inter run fusion has occurred during the welding of one of the pipes to pipe circumferential seams. Which of the following NDT methods would best detect this defect

- a. MPI or DPI as this defect is usually surface breaking
- b. RT would be best suited to detect this defect if no slag was present
- c. UT would be best suited to detect this defect if no slag was present
- d. 2 options are correct

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Question 9

Some codes and standards only permit weld repairs to be conducted for a minimum amount of times before a full cut out is required. Why do you think this is the case?

- a. If a weld is repaired an unlimited amount of times it may affect the mechanical and metallurgical properties of the weld
- b. The amount of preheat will be too high for the welder to weld
- c. A critical post heat treat will always be required
- d. It would be difficult to find approved welders to conduct these type of repairs

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Question 10

One of your welding inspectors asks you what is the minimum depth a weld repair excavation needs to be. Which of the following would be your answer?

- a. The thickness of the base material.
- b. As deep as it is required to ensure the defect has been fully removed
- c. The depth would depend on the radiography interpretation report
- d. 2 options are correct

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Appendix 1

Homework

Senior Welding Inspection: Multiple Choice Questions

Paper 1

Name: **Date:**

- 1 Which is the best destructive test for showing lack of sidewall fusion in a 25mm thickness butt weld?
 - a Nick break.
 - b Side bend.
 - c Charpy impact.
 - d Face bend test.
- 2 Which of the following would be cause for rejection by most fabrication standards when inspecting fillet welds with undercut, a small amount of?
 - a Depth.
 - b Length.
 - c Width.
 - d Sharpness.
- 3 The European Standard for NDE of fusion welds by visual examination is:
 - a BS EN ISO 15614.
 - b BS EN ISO 2560.
 - c BS EN 287.
 - d BS EN ISO 17637.
- 4 When visually inspecting the face of a finished weld which of the following flaws would be considered the most serious:
 - a Excess weld metal height.
 - b Start porosity.
 - c Spatter.
 - d Arc strikes.
- 5 Which of the following is a planar imperfection?
 - a Lack of sidewall fusion.
 - b Slag inclusion.
 - c Linear porosity.
 - d Root concavity.
- 6 A fillet weld has an actual throat thickness of 8mm and a leg length of 7mm, what is the excess weld metal?
 - a 2.1mm.
 - b 1.8mm.
 - c 3.1mm.
 - d 1.4mm.

- 7 BS EN ISO 17637 allows the use of a magnifying glass for visual inspection, but recommends that the magnification is:
- a x2.
 - b x2 to x5.
 - c x5 to x10.
 - d Not greater than x20.
- 8 A WPS may specify a maximum width for individual weld beads (weave width) when welding C-Mn steels. If the width is exceeded it may cause:
- a Lack of inter-run fusion.
 - b A reduction in HAZ toughness.
 - c Lack of sidewall fusion.
 - d Too low a deposition rate.
- 9 In TIG welding a current slope-out device reduces:
- a Tungsten spatter.
 - b Risk of crater cracking.
 - c Risk of arc strikes.
 - d Interpass temperature.
- 10 Pipe bores of some materials must be purged with argon before and during TIG welding to:
- a Prevent linear porosity.
 - b Prevent burn-through.
 - c Prevent oxidation of the root bead.
 - d Eliminate moisture pick-up in the root bead.
- 11 According to AWS A2.4 a weld symbol for the other side is placed:
- a Above the dashed line.
 - b Below the dashed line.
 - c Above the solid line.
 - d Below the solid line.
- 12 Which of the following elements is added to steel to give resistance to creep at elevated service temperatures?
- a Nickel.
 - b Manganese.
 - c Molybdenum.
 - d Aluminium.
- 13 Compound welds:
- a Always contain full penetration butt welds.
 - b Joints which have combinations of welds made by different welding processes.
 - c Combinations between two different weld types.
 - d All of the above.

- 14 Welding inspectors:
- a Normally supervise welders.
 - b Are normally requested to write welding procedures.
 - c Are sometimes requested to qualify welders.
 - d All of the above.
- 15 In an arc welding process, which of the following is the correct term used for the amount of weld metal deposited per minute?
- a Filling rate.
 - b Deposition rate.
 - c Weld deposition.
 - d Weld duty cycle.
- 16 The throat thickness of 19mm fillet weld is?
- a 27.5mm.
 - b 24mm.
 - c 13.3mm.
 - d 12.5mm.
- 17 Pre-heat for steel will increase if:
- a The material thickness reduces.
 - b Faster welding speeds.
 - c The use of a larger welding electrode.
 - d A reduction in carbon content in the parent material.
- 18 What is the maximum allowable linear misalignment for 8mm material if the code states the following, '*Linear misalignment is permissible if the maximum dimension does not exceed 10% of t up to a maximum of 2mm*'?
- a 0.8mm.
 - b 2mm.
 - c 8mm.
 - d None of the above, insufficient information provided.
- 19 BS EN ISO 17637:
- a The minimum light illumination required for visual inspection is 350 Lux.
 - b The minimum light illumination required for visual inspection is 500 Lux.
 - c The minimum light illumination required for visual inspection is 600 Lux at not less than 30°.
 - d Doesn't specify any viewing conditions for visual inspection.
- 20 Which of the following electrodes and current types may be used for the TIG welding of nickel and its alloys?
- a Cerium electrode, DC -ve.
 - b Zirconium electrode, AC.
 - c Thorium electrode, DC +ve.
 - d All of the above may be used.

- 21 When considering the MIG/MAG welding process which of the following metal transfer modes would be the most suited to the welding of thick plates over 25mm in PA.
- a Dip transfer.
 - b Pulse transfer.
 - c Spray transfer.
 - d Globular transfer.
- 22 When considering hydrogen, which of the following welding processes would produce the lowest levels in the completed weld? (under controlled conditions)
- a MMA.
 - b SAW.
 - c TIG.
 - d FCAW.
- 23 In steel the element with the greatest effect on hardness is:
- a Chromium.
 - b Manganese.
 - c Carbon.
 - d Nickel.
- 24 Brittle fractures:
- a The susceptibility in steels will increase with the formation of a fine grain structure.
 - b The susceptibility in steels will increase with a reduction in the in-service temperature to sub-zero conditions.
 - c The susceptibility in steels will increase with a slow cooling rate.
 - d All of the above.
- 25 Which of the following steels is considered non-magnetic?
- a 18%Cr, 8%Ni.
 - b 2.25Cr 1Mo.
 - c 9%Cr, 1Mo.
 - d 9%Ni.
- 26 In a transverse tensile test brittleness would be indicated if:
- a There is a reduction in cross-section at the position of fracture.
 - b The fracture surface is flat and featureless but has a rough surface.
 - c Fracture occurred in the weld metal.
 - d The fracture face shows beach marks.
- 27 A STRA test is used to measure the:
- a Tensile strength of the welded joint.
 - b Level of residual stress in butt joints.
 - c Fracture toughness of the HAZ.
 - d Through-thickness ductility of a steel plate (the Z direction).

- 28 A macrosection is particularly good for showing:
- a The weld metal HAZ microstructure.
 - b Overlap.
 - c Joint hardness.
 - d Spatter.
- 29 A suitable gas/gas mixture for GMAW of aluminium is:
- a 100%CO₂.
 - b 100% Argon.
 - c 80% argon + 20% CO₂.
 - d 98% argon + 2% O₂.
- 30 A crack running along the centreline of a weld bead could be caused by:
- a Use of damp flux.
 - b Lack of preheat.
 - c Arc voltage too high.
 - d Weld bead too deep and very narrow.

Senior Welding Inspector: Multiple Choice Questions

Paper 2

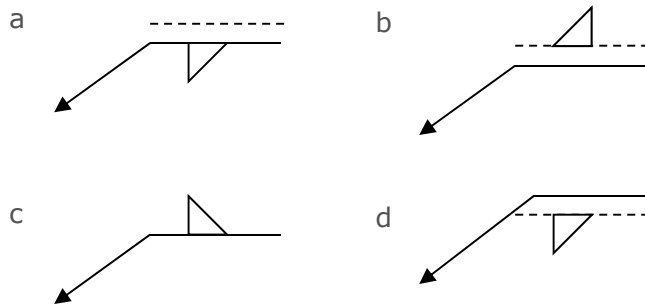
Name: Date:

- 1 The maximum hardness in the HAZ of a steel will increase if:
 - a Heat input is increased.
 - b CEV is increased.
 - c Joint thickness is decreased.
 - d Basic electrodes are used.
- 2 Initiation of a TIG arc using a high frequency spark may not be allowed because it:
 - a Often causes tungsten inclusions.
 - b Can damage electronic equipment.
 - c Is an electrical safety hazard.
 - d Often causes stop/start porosity.
- 3 In friction welding, the metal at the interface when the joining occurs is described as being in the:
 - a Liquid state.
 - b Intercritical state.
 - c Plastic state.
 - d Elastic state.
- 4 What four criteria are necessary to produce hydrogen induced cold cracking?
 - a Hydrogen, moisture, martensitic grain structure and heat.
 - b Hydrogen, poor weld profiles, temperatures above 200°C and a slow cooling rate.
 - c Hydrogen, a grain structure susceptible to cracking, stress and a temperature below 300°C.
 - d Hydrogen, existing weld defects, stress and a grain structure susceptible to cracking.
- 5 Austenitic stainless steels are more susceptible to distortion when compared to ferritic steels this is because:
 - a High coefficient of thermal expansion, low thermal conductivity.
 - b High coefficient of thermal expansion, high thermal conductivity.
 - c Low coefficient of thermal expansion, high thermal conductivity.
 - d Low coefficient thermal expansion, low thermal conductivity.
- 6 Transverse tensile test:
 - a Is used to measure the ultimate tensile strength of the joint.
 - b Is used to measure the elongation of a material.
 - c Is used to measure the yield strength of a material.
 - d All of the above.

- 7 In the welding of austenitic stainless steels, the electrode and plate materials are often specified to be low carbon content. The reason for this:
- a To prevent the formation of cracks in the HAZ.
 - b To prevent the formation of chromium carbides.
 - c To prevent cracking in the weld.
 - d Minimise distortion.
- 8 Essential variable:
- a In a WPS may change the properties of the weld.
 - b In a WPS may influence the visual acceptance.
 - c In a WPS may require re-approval of a weld procedure.
 - d All of the above.
- 9 In an all weld metal tensile test, the original test specimens gauge length is 50mm. After testing the gauge length increased to 72mm, what is the elongation percentage?
- a 44%.
 - b 144%.
 - c 69.4%.
 - d 2.27%.
- 10 Which of the following will vary the most when varying the arc length using the MMA welding process?
- a Voltage.
 - b Amperage.
 - c Polarity.
 - d Both a and b.
- 11 An undesirable property of aluminium oxide residue is that it:
- a Creates problems when welding in position (vertical, horizontal, overhead).
 - b Requires more heat to melt it when compared with aluminium.
 - c Increases weld pool fluidity.
 - d Decreases weld pool fluidity.
- 12 A welder qualified in the PG position would normally be qualified for welding:
- a All diameters of pipe.
 - b Welding positions PA, PC, PG, and PF.
 - c In position PG only.
 - d All pipe wall thickness.
- 13 A fabrication calls for the toes to be blended in by grinding. The most likely reason for this is to...
- a Make the weld suitable for liquid (dye) penetrant inspection
 - b Improve the fatigue life
 - c reduce residual stresses
 - d improve the general appearance of the welds

- 14 A carbon equivalent of 0.48%:
- a Is high for carbon steel and may require a preheat temperature over 100°C.
 - b Is insignificant for carbon steel and preheat will not be required.
 - c Is calculated from the heat-input formula.
 - d Is not a consideration for determining preheating temperatures.
- 15 Which of the following statements is true?
- a The core wire of an MMA electrode always contains alloying elements.
 - b Basic electrodes are preferred when welding is carried out in situations where porosity free welds are specified.
 - c Rutile electrodes always contain a large proportion of iron powder.
 - d Cellulose electrodes may deposit in excess of 90ml of hydrogen per 100g of weld metal.
- 16 Preheat:
- a Must always be carried out on steels.
 - b Need not be carried out if post weld heat is to follow.
 - c Is always carried out using gas flames.
 - d None of the above.
- 17 Which element has the greatest effect on general corrosion resistance?
- a Manganese.
 - b Chromium.
 - c Carbon.
 - d Nickel.
- 18 Which of the following is the correct arc energy if the amps are 350, volts 32 and travel speed 310 mm/minute.
- a 2.16 kJ/mm.
 - b 0.036 kJ/mm.
 - c 2.61 kJ/mm.
 - d 0.36 kJ/mm.
- 19 Which of the following mechanical test(s) can give a quantitative measurement of ductility?
- a Tensile test.
 - b Bend test
 - c Nick break test.
 - d Both a and b.
- 20 Which of the following are applicable to fatigue cracking?
- a A rough randomly torn fracture surface, an initiation point and beach marks.
 - b A smooth fracture surface, an initiation point and beach marks.
 - c Beach marks, step like appearance and a secondary mode of failure.
 - d All of the above.

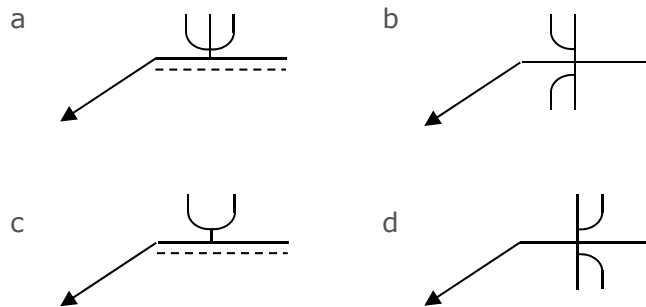
- 21 Which of the following weld symbols in accordance with BS EN ISO 2553 represents a fillet weld made on the other side?



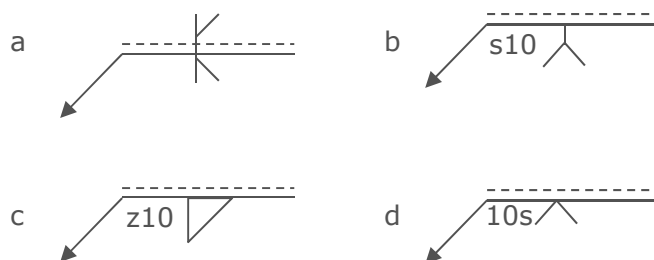
- 22 What is a lap in steel?

- a A fold occurring in the steel during forming or rolling.
- b A sub-surface lamination, which may affect the strength of the steel.
- c A type of crack occurring in the parent material.
- d A non-metallic inclusion.

- 23 In accordance with BS EN ISO 2553 which of the following symbol best represents a double J butt weld?



- 24 Which of the following welding symbols would indicate the depth of penetration in accordance with BS EN ISO 2553?



- 25 How can you tell the difference between an EN/ISO weld symbol and an AWS weld symbol?
- a The EN/ISO weld symbol will always have the arrow side weld at the top of the reference line.
 - b The EN/ISO symbol has the welds elementary symbol placed on the indication line lying above or below the solid reference line to indicate a weld on the other side.
 - c The EN/ISO symbol has a fillet weld leg length identified by the letter 'a'.
 - d The EN/ISO symbol has a fillet weld throat thickness identified by the letter 'z'.
- 26 What would the number 141 placed at the end of the reference line indicate on a welding symbol in accordance with BS EN ISO 2553?
- a NDT requirements.
 - b SAW welding process.
 - c MMA welding process.
 - d TIG welding process.
- 27 What would the number 136 placed at the end of the reference line indicate on a welding symbol in accordance with BS EN ISO 2553?
- a MMA welding process.
 - b MIG welding process.
 - c FCAW welding process.
 - d MAG welding process.
- 28 What is meant by the term *normative document*?
- a General term used to cover standards, specifications etc.
 - b A legal document, the requirements of which must be carried out.
 - c A document approved by a recognised body through consensus.
 - d A written description of all essential parameters for a given process.
- 29 In the AWS standard for welding symbols which of the following is true.
- a The elementary welding symbol is always placed below the reference line to indicate a site weld.
 - b The elementary welding symbol is always placed above the reference line to indicate a weld made on the arrow side.
 - c The elementary welding symbol can be placed above or below the reference line to indicate a weld made on the other side.
 - d The elementary welding symbol is always placed below the reference line to indicate a weld made on the arrow side.
- 30 Impact test:
- a Is a destructive test used to measure weld zone hardness.
 - b Is a mechanical test used to determine a welds resistance to creep.
 - c Is a dynamic test, which is used to give a measure of notch toughness.
 - d All of the above.

Senior Welding Inspector: Multiple Choice Questions

Paper 3

Name: Date:

- 1 If arc strikes are found on carbon steel (carbon equivalent of 0.5%), what undesirable grain structure may be present?
 - a Pearlite.
 - b Martensite.
 - c Ferrite.
 - d All of the above are undesirable grain structures in constructional steels.
- 2 Which of the following units is used to express the energy absorbed by a charpy specimen?
 - a Joules.
 - b Newton's.
 - c Mega Pascal's.
 - d Both a and c.
- 3 What does the 70 represent on an E7010 AWS A5.1 classified electrode?
 - a 70 N/mm² minimum UTS.
 - b 70N/mm² minimum impact strength.
 - c 70,000 p.s.i. minimum UTS.
 - d 70,000 p.s.i. minimum yield strength.
- 4 A multi-run MMA butt weld made on low alloy steel consists of 5 passes using a 6mm diameter electrode, a 12 pass weld made on the same joint using a 4mm diameter electrode on the same material will:
 - a Have a lower heat input and a higher degree of grain refinement.
 - b Have a lower heat input and a coarse grain structure.
 - c Have a lower amount of distortion and a higher degree of grain refinement.
 - d Have a higher amount of distortion and a lower degree of grain refinement.
- 5 Which of the following would you expect of a martensitic grain structure?
 - a An increase in toughness and a reduction in hardness.
 - b An increase in hardness and a reduction in ductility.
 - c An increase in ductility and a reduction in toughness.
 - d An increase in malleability and an increase in hardness.
- 6 Which of the following would reduce the chances of arc blow?
 - a A change from AC current to DC current.
 - b A change from DC current to AC current.
 - c A change from DC electrode +ve to DC electrode -ve.
 - d A change from DC electrode -ve to DC electrode +ve.

- 7 Which of the following mechanical properties of a weld made on C-Mn steel is most affected if the heat input per unit length is excessively high?
- a Tensile strength.
 - b Ductility.
 - c Toughness.
 - d Elongation.
- 8 Which of the following tests would you not expect to be carried out on a welder qualification test?
- a Radiography.
 - b Tensile test.
 - c Macro.
 - d Bend test.
- 9 Which two aspects of radiographic images are normally measured?
- a Density and contrast.
 - b Sensitivity and definition.
 - c Density and sensitivity.
 - d Contrast and definition.
- 10 What are the units used when measuring light intensities for viewing test specimens using MPI or DPI testing?
- a Tesla.
 - b Lux.
 - c Hertz.
 - d Gray.
- 11 If it was a requirement to radiograph a 10mm thick steel weldment, which of the following isotopes would be the most suited with regards to application and quality?
- a Se 75.
 - b Tm 170.
 - c Yb 169
 - d Co 60.
- 12 When carrying out inspection on a Double V butt weld (35° bevel angle), which of the following NDT methods would be the most suited for the detection of lack of sidewall fusion in the root region?
- a Ultrasonic Inspection.
 - b Radiographic Inspection.
 - c Magnetic Particle Inspection.
 - d Dye Penetrant Inspection.
- 13 Which NDT method would you associate with prods?
- a Radiographic Inspection.
 - b Magnetic Particle Inspection.
 - c Ultrasonic Inspection.
 - d Dye Penetrant Inspection..

- 14 When conducting DPI, which of the following are critical considerations?
- a Thickness of component being tested.
 - b Weld preparation details.
 - c Components test temperature.
 - d All of the above.
- 15 Which material would be the least effective for DPI?
- a Carbon Manganese steels.
 - b 316L steel.
 - c Cast Iron.
 - d Both a and c.
- 16 Why might Iron powder be used when conducting MPI?
- a If the component being tested is too large for regular inks to be used.
 - b During the inspection of components underwater.
 - c During the inspection of hot components.
 - d Iron powder is preferred over regular MPI inks due to the higher sensitivity achieved and ease of application.
- 17 During MPI inspection using contrast inks, what is the minimum light intensity requirements in accordance with the EN standards?
- a The same as that required for visual inspection.
 - b 350 lux minimum, 500 lux recommended.
 - c 500 lux.
 - d Not specified, it's left to the decision of the NDT technician.
- 18 A major disadvantage of MPI is:
- a It can only be used on material over 3mm thickness.
 - b It can only detect surface defects.
 - c It can only be used on ferrous materials.
 - d Both b and c.
- 19 What is the main purpose of an IQI when used in Radiography?
- a To measure defect sensitivity.
 - b To assess the smallest defect which can be detected.
 - c To measure Radiographic sensitivity.
 - d All of the above.
- 20 Back step welding is used to reduce:
- a Distortion.
 - b Stress corrosion cracking.
 - c Fatigue failure.
 - d Solidification cracking.

- 21 Which of the following materials will show the greatest amount of distortion, assuming heat inputs, material thickness etc. are the same?
- a High tensile strength C/Mn steel.
 - b Mild steel.
 - c 316L steel.
 - d QT steel.
- 22 HICC may occur due to which of the following?
- a Damp electrodes.
 - b Lack of preheat.
 - c The presence of sulphur.
 - d Both a and b.
- 23 The likelihood of hydrogen cracking in a carbon steel weld can be reduced by:
- a The use of E6010 or E6011 electrodes.
 - b Keeping preheat to a minimum.
 - c The maintenance of minimum heat inputs.
 - d None of the above.
- 24 Distortion can be reduced by:
- a The use of a large bevel angle.
 - b The use of basic coated electrodes.
 - c The use of small diameter electrodes, maximise the number of weld passes.
 - d The use of large diameter electrodes, minimise the number of weld passes.
- 25 A duty not normally undertaken by a Senior Welding Inspector:
- a Check incoming materials.
 - b Check and monitor consumable handling and storage.
 - c Check calibration certificates.
 - d Measure and monitor residual stress.
- 26 The inclusion of the inductance in the welding circuit when using the MIG/MAG welding process is to:
- a Control the rate of spatter in the dip transfer mode.
 - b Control the rate of spatter in the spray transfer mode.
 - c It enables the welder to weld in position at higher current values.
 - d Both a and b.
- 27 What is 'weld decay'?
- a A localised reduction in chromium content caused by sulphur and chromium combining in SS.
 - b A localised reduction in chromium content caused by iron and chromium combining in SS.
 - c A localised reduction in chromium content caused by carbon and chromium combining in SS.
 - d A reduction in tensile strength of a material operating at elevated temperatures under a constant load, which generally leads to a failure of the component in SS.

- 28 What are the possible effects of having the heat input too low during welding?
- a Low toughness, entrapped hydrogen and low hardness.
 - b High hardness, lack of fusion and entrapped hydrogen.
 - c Entrapped hydrogen, low toughness and high ductility.
 - d Lack of fusion, low toughness and a reduction in ductility.
- 29 Which of the following Isotopes may be used for a 25mm thick steel pipe to pipe weld DWSI (in accordance to BS EN ISO 17636-1)?
- a Ir 192.
 - b Co 60.
 - c Se 75.
 - d Yb 169.
- 30 During a the welding of a test piece for the purpose of approving a WPS the following parameters have been recorded: Amps 300, Volts 32, ROL 210mm, time 1 minute. What is the arc energy value?
- a 4.1 KJ/mm.
 - b 7.38 KJ/mm.
 - c 6.4 KJ/mm.
 - d 2.74 KJ/mm.

Senior Welding Inspector: Multiple Choice Questions

Paper 4

Name: Date:

Magnetic Particle Testing (MT)

- 1 Which of the following materials cannot be tested using MT?
 - a Cobalt.
 - b Nickel.
 - c Carbon steel.
 - d Brass.
- 2 Suspending magnetic particles in a liquid has the advantage of:
 - a Making the same amount of detection media go further.
 - b Improving particle mobility.
 - c Preventing corrosion.
 - d Improving contrast.
- 3 Magnetic particles for use in magnetic ink are generally made from:
 - a Iron oxide.
 - b Ferrous sulphate.
 - c Aluminium oxide.
 - d A special high nickel alloy
- 4 Maximum sensitivity in MT is achieved when the:
 - a Flaw is at right angles to the direction of the current.
 - b Flaw is parallel to the magnetic flux.
 - c Flaw is at right angles to the magnetic flux.
 - d Current is at right angles to the magnetic flux.
- 5 When MPI is performed with fluorescent ink, the maximum level of white light illumination that must be present at the area under inspection is:
 - a 50 lux.
 - b 500 lux
 - c 2000 microwatts per square millimetre.
 - d 20 lux.
- 6 Which of the following statements about the use of permanent magnets for MT is true?
 - a They require no power supply.
 - b They are ideal for use with dry magnetic particles.
 - c They provide excellent sensitivity for surface breaking defects.
 - d They give the clearest indications of discontinuities lying parallel to a line joining the magnet poles.

- 7 The region in the neighbourhood of a permanent magnet or current carrying device in which magnetic forces exist is called a:
- a Magnetic circuit.
 - b Magnetic field.
 - c Leakage field.
 - d Magnetic pole.
- 8 The general name given to a simple device used in MPI to indicate field strength and direction is:
- a Flux indicator.
 - b Gauss meter.
 - c Magnetometer.
 - d Dynamometer.
- 9 The flash point of a solvent is:
- a The temperature above which there is a danger of spontaneous combustion of the solvent vapour.
 - b It's boiling point.
 - c The temperature below which there is a danger of spontaneous combustion of the solvent vapour.
 - d The temperature above which the solvent becomes soluble in water.
- 10 The temperature above which a ferromagnetic material becomes nonmagnetic is called the:
- a Breaking point.
 - b Curie point.
 - c Sharp point.
 - d Turning point.

Penetrant Testing (PT)

- 11 A disadvantage of penetrant flaw detection is that:
- a It can only detect surface breaking discontinuities.
 - b It cannot be used on fine cracks such as fatigue cracks.
 - c Parts cannot be re-tested.
 - d It cannot be used on non-ferrous materials.
- 12 An advantage of penetrant flaw detection is that:
- a It can be used on non-ferromagnetic materials.
 - b Fluorescent penetrant can be used for on-site testing of large parts.
 - c The temperature of the part need not be considered.
 - d Painted parts can be rapidly tested.
- 13 European national codes and standards do not normally permit the penetrant method to be used outside what temperature range?
- a 10-55 C.
 - b 15-50 C.
 - c 10-50 C.
 - d 5-60 C.

- 14 An advantage of colour contrast penetrants over fluorescent penetrants is that they:
- a Are more sensitive because the indications are easier to see.
 - b Do not require special removers.
 - c Are more suitable for smooth surfaces.
 - d Do not require an electrical power supply.
- 15 Typically, when fluorescent penetrants are used:
- a The inspector should allow a few minutes before starting inspection to allow night vision to develop.
 - b The quantity of white light in the inspection booth should be limited to around 20lux.
 - c Removal of excess penetrant is monitored under UV-A light.
 - d All of the above.
- 16 Which of the following discontinuities would be impossible to detect using the penetrant method?
- a Forging laps.
 - b Grinding cracks.
 - c Non-metallic internal inclusions.
 - d Crater cracks.
- 17 When selecting which penetrant system to employ which of the following factors must be considered?
- a Component surface finish.
 - b The sensitivity required.
 - c The compatibility of the penetrant with the material under inspection.
 - d All of the above must be considered.
- 18 Which of the following statements concerning liquid penetrant testing is correct?
- a Fluorescent penetrants will produce red against white discontinuity indications.
 - b Non-fluorescent penetrants require the use of black lights.
 - c Yellow-green fluorescent indications glow in the dark for easy viewing and interpretation.
 - d Fluorescent penetrants produce yellow green visible light under UV-A illumination.
- 19 Development time is influenced by the:
- a Type of penetrant used.
 - b Type of developer used.
 - c Temperature of the material being tested.
 - d All of the above.
- 20 Factors that affect the rate of penetration include:
- a Surface temperature.
 - b Surface condition & cleanliness.
 - c Viscosity.
 - d All of the above.

Ultrasonic Testing (UT)

- 21 The process of comparing an instrument or device with a standard is called:
- a Angulation.
 - b Calibration.
 - c Attenuation.
 - d Correlation.
- 22 The piezoelectric material in a probe, which vibrates to produce ultrasonic waves, is called a:
- a Backing material.
 - b Lucite wedge.
 - c Transducer element or crystal.
 - d Couplant.
- 23 Moving a probe over a test surface either manually or automatically is referred to as:
- a Scanning.
 - b Attenuation.
 - c Angulating.
 - d Resonating.
- 24 The purpose of a couplant is to:
- a Filter undesirable reflections from the specimen.
 - b Tune transducer to the correct operating frequency.
 - c Reduce attenuation within the specimen.
 - d Transmit ultrasonic waves from the transducer to the specimen.
- 25 A couplant can be:
- a Water.
 - b Oil.
 - c Glycerin
 - d Any of the above.
- 26 The primary purpose of reference blocks is:
- a To aid the operator in obtaining maximum back reflection.
 - b To obtain the greatest sensitivity possible from an instrument.
 - c To obtain a common reproducible reference standard.
 - d None of the above is correct.
- 27 The gradual loss of energy as ultrasonic vibrations travel through a material is referred to as:
- a Attention.
 - b Attendance.
 - c Attemperation.
 - d Attenuation.

- 28 Any condition that causes reflection of ultrasound in pulse echo testing can be referred to as:
- a A dispenser.
 - b A discontinuity.
 - c An attenuator.
 - d A refractor.
- 29 If the cap of a single V (60° included angle) full penetration butt-weld is ground flush 0 degree compression probe is useful for:
- a Detecting lack of side wall fusion.
 - b Detecting lack of root fusion.
 - c Assessing excess penetration.
 - d All of the above.
- 30 Welds in austenitic stainless steel:
- a Are easily tested by ultrasonic methods.
 - b Are difficult to test by ultrasonic methods due to the coarse grain structure of the weld deposit.
 - c Are difficult to test by ultrasonic methods due to the highly attenuating parent material.
 - d Both b and c are correct.

Radiographic Testing (RT)

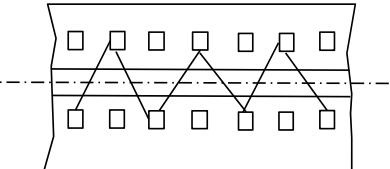
- 31 The two factors that most affect the sensitivity of a radiograph are:
- a Density and unsharpness.
 - b Latitude and grain size.
 - c Density and latitude.
 - d Contrast and definition.
- 32 The instrument used to measure film density is called:
- a A densitometer.
 - b A photometer.
 - c A radiometer.
 - d A proportional counter.
- 33 Compared with conventional ultrasonic testing one advantage of film radiography is:
- a It's cheaper.
 - b A permanent record is directly produced.
 - c Lack of fusion is easily detected.
 - d All of the above are significant advantages.
- 34 Which of the following weld defects is most reliably detected by radiography?
- a Porosity.
 - b Lack of inter-run fusion.
 - c Lack of root fusion.
 - d Heat affected zone crack.

- 35 Which of the following weld defects is least reliably detected by radiography?
- a Porosity.
 - b Slag inclusion.
 - c Lack of penetration.
 - d Heat affected zone crack.
- 36 Radiography is a reliable method for the detection of:
- a Volumetric flaws.
 - b Planar flaws.
 - c Both volumetric and planar flaws.
 - d Laminations in rolled steel products.
- 37 DWDI radiography is usually limited to girth welds in pipe with an outside diameter of (consider EN ISO standard):
- a 75mm or less.
 - b 80mm or less.
 - c 85mm or less.
 - d 100mm or less.
- 38 Radiography is best suited for:
- a Cruciform joints.
 - b Dissimilar welds.
 - c T butt welds.
 - d Set through joints
- 39 The correct terminology for the image that forms on a radiographic film during exposure to radiation is:
- a Ghost image.
 - b Latent image.
 - c Patent image.
 - d Spitting image.
- 40 If detected by radiography undercut appears as:
- a A very thin, continuous or intermittent, straight dark line running parallel with the edge of the weld cap.
 - b A broad straight edged image towards the centre of the weld image.
 - c A dark line of variable width, continuous or intermittent, between the weld & parent material & following the contour of the edge of the weld cap or root.
 - d A dark irregular image, within the weld image, continuous or intermittent, of variable width and film density running essentially parallel to the weld axis

Appendix 2

Training Reports

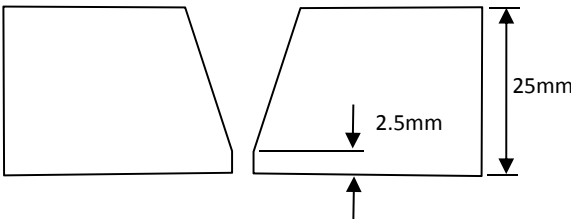
CSWIP 3.2 TRAINING REPORT MT 01

INSPECTION COMPANY: TWI NDT		REPORT NUMBER: 01 PROJECT NUMBER: 1970	
CLIENT: Tramcar		WELD NUMBER: 48	
SPECIFICATION: TWI NDT specification		WELD DETAILS: Single V butt weld weld number	
TECHNIQUE 132/T		SURFACE CONDITION: As welded	
PROCEDURE NUMBER: 132		WELDING PROCESS: 111	
DATE OF EXAMINATION: 4.8.15		SCOPE OF INSPECTION: 100% of weld and HAZ	
LOCATION: Prenton Park workshop		PROCESS STAGE: After PWHT	
MATERIAL:ASTM 182		LIFT TEST COMPLETED: YES @ 5.4 KG	
CONSUMABLES	MANUFACTURER	TYPE	BATCH NUMBERS
Solvent based ink	Magnaflux	7HF	120514
Contrast Paint	Magnaflux	WCP-2	150415
Solvent Remover	Magnaflux	SKC-S	140905
	TESTING TECHNIQUE: AC Yoke		
	TEMPERATURE:Ambient		
	LIGHT LEVELS: >350Lux at test surface		
	TEST SENSITIVITY: 3 indications, Burmah castrol strip		
	CURRENT TYPE: DC		
POLE SPACING: 50 mm			
TEST RESULTS:			
No defects detected No reportable indications detected			
ACTION:			
No further actions			
OPERATORS NAME: S Jones		REPORT DATE: 4.8.15	
OPERATORS SIGNATURE: <i>S Jones</i>		OPERATORS QUALIFICATION: CSWIP Level 2 MPI	

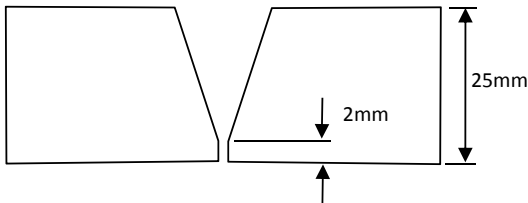
CSWIP 3.2 TRAINING REPORT PT 01

INSPECTION COMPANY: TWI NDT		REPORT NUMBER: 0011 PROJECT NUMBER: 1970	
CLIENT: Tramcar		WELD NUMBER: 69	
SPECIFICATION: CSWIP		WELD DETAILS: Single V Butt joint weld	
TECHNIQUE 132/PT		SURFACE CONDITION: As welded	
PROCEDURE NUMBER: 132		WELDING PROCESS: 141	
DATE OF EXAMINATION: 8.4.15		SCOPE OF INSPECTION: 100%	
LOCATION: Prenton Park workshop		PROCESS STAGE: Completed	
MATERIAL: 316 SS		VIEWING CONDITIONS: >500Lux	
CONSUMABLES	MANUFACTURER	TYPE	BATCH NUMBERS
Solvent Remover	Magnaflux	7HF	120514
Penetrant	Magnaflux	SKL-SP2	150415
Developer	Magnaflow	SKC-S	140905
APPLICATION: Brush			
DWELL TIME: 20 minutes			
DEVELOPMENT TIME: 10 minutes			
		TEST TEMPERATURE: 5-10 °C	
TEST RESULTS			
ACTIONS			
SIGNATURE: <i>D Pennar</i>		REPORT DATE: 8.4.15	
NAME: Dye Pennar		QUALIFICATION: CSWIP LT2 PT (ISO 9712)	

CSWIP 3.2 TTRAINING REPORT RT 01

DATE OF INSPECTION: 4.8.15		INSPECTION COMPANY: TWI NDT		
REPORT NUMBER: 1970		CLIENT: Tramcar		
WELDING PROCESS: MMA 111		WELD REFERENCE: 47		
JOINT GEOMETRY  - Bevel Angle 30° + 5°, - 0° - Root Gap 2.5mm. - Plate thickness 30 mm - Weld Length		SURFACE CONDITION: As welded MMA 111		
		TEST PROCEDURE: 131		
		STAGE OF TEST: After PWHT		
		SCOPE OF INSPECTION: 100%		
		MATERIAL: C-Mn		
		Source Strength: 60 Ci	FFD/SFD: 150 mm	
		KV's: N/A	mA's: N/A	
		Screen type: Pb	Exposure: 4Ci mins	
Focal Spot:		Source Size: 2x2		
FILM TYPE: AGFA D4		IQI TYPE: Fe		
DEVELOPMENT: 4 mins @ 20°C manual		FIXING CONDITIONS 6 mins @ 20°C		
RADIOGRAPHIC TECHNIQUE: SWSI		ISOTOPE TYPE: Ir 192		
TEST RESULTS				
FILM ID	SEN %	DENSITY	COMMENTS	ACTION
1-2	2%	2-3	No defects observed	Accept
2-3	2%	2-3	No defects observed	Accept
3-4	2%	2-3	No defects observed	Accept
4-5	2%	2-3	No defects observed	Accept
5-6	2%	2-3	lack of root penetration	Reject
TEST LIMITATIONS:				
TEST OPERATOR: S Jones		REPORT DATE: 4.8.15		
SIGNATURE: S Jones		OPERATORS QUALIFICATION: CSWIP L2 RT (EN ISO9712)		

CSWIP TRAINING REPORT UT01

INSPECTION COMPANY: TWI NDT		CLIENT: Tramcar	
PROJECT NUMBER: 267		REPORT NUMBER: 256	WELD NUMBER: 24
PROJECT LOCATION: Prenton Workshop		DATE OF INSPECTION: 4.8.15	
JOINT GEOMETRY  – Root Gap 2mm. – Root to be inspected by MT before commencement of next weld pass		SCOPE OF INSPECTION: 100%	
		MATERIAL: Aluminium 5083	
		DIMENSIONS: 700mm L FORM: Plate	
		SURFACE CONDITION: As welded	
		WPS: 0069 GTAW TEMPERATURE : Ambient	
		TEST PROCEDURE: 14	
		DETECTION UNIT: KSM SERIAL NUMBER: 6754	
COUPLANT: Sonagel			
CALIBRATION BLOCKS: V1,V2			
PROBES	SIZE	SENSITIVITY	SCANNING
5 MHz 0° Compression	10mm Twin Crystal	BWE 80% F.S.H At test depth	At test sensitivity
4 MHz 45° Shear	10mm Single Crystal	80% F.S.H 1.5mm Hole	At test sensitivity
4 MHz 60° Shear	10mm Single Crystal	80% F.S.H 1.5mm Hole	At test sensitivity
4 MHz 70° Shear	10mm Single Crystal	80% F.S.H 1.5mm Hole	At test sensitivity
TEST RESULTS: BS EN ISO 17640:2010			
1. Crack like indication detected with 60° shear wave scanning in root location. 2. Slag inclusions detected with 45° shear wave scanning			
ACCEPTANCE:TWI NDT SPECIFICATION			
Not accptabe			
NAME: M Rogers		SIGNATURE: 	
LEVEL OF QUALIFICATION: CSWIP L2 UT EN ISO 9712		REPORT DATE: 4.8.15	

Senior Welding Inspector: Training Reports Questions

Name: Date:

MT01 Questions

- 1 The lift test stated in MT01
 - a Is not required if test sensitivity is recorded
 - b Complies with specification and is common practice
 - c Lift testing is for permanent magnets only
 - d Does not comply with the specification

- 2 Do you consider the scanning pattern shown to be
 - a Correct and fully compliant with the procedure
 - b Missing the dimensions for each span of the yoke conducted
 - c Incorrect and not compliant with the specification
 - d This type of scanning is only applicable to AC

- 3 In relation to the light levels reported on MT01, is it stated correctly and which is the correct statement?
 - a Yes, as so long as you have valid eye test and have completed competency checks
 - b Yes, it states a minimum of 350 Lux but recommends 500 Lux
 - c No, 350 Lux is for black light not white light
 - d No, 500 Lux is the minimum permitted light intensity

- 4 Which of the following statements is correct?
 - a Pole spacing is 300mm minimum
 - b Pole spacing is 300mm maximum
 - c Pole spacing is 150mm maximum
 - d Pole spacing depends on the power of the Yoke

- 5 Which of the following statements is correct?
 - a AC Yokes only shall be reported
 - b DC yokes shall be used in all situations
 - c According to the TWI specification DC shall be used on raw materials but not welds
 - d Permanent magnets shall be used on live plant and AC on non-live plant

PT01 Questions

- 6 In accordance with the TWI specification, at which of the following temperatures is penetrant inspection permissible
- a Between 1°C and 10°C
 - b Between 5°C and 10°C
 - c Between 5°C and 50°C
 - d Between 25°C and 40°C
- 7 Do you consider the development time stated in PT01 as
- a Acceptable to the TWI specification as no maximum is stated
 - b Not acceptable to the TWI specification
 - c A suitable period as to compliment the dwell time
 - d All options are incorrect
- 8 In accordance with the TWI Specification is the material type stated on PT01 acceptable
- a Yes it is acceptable
 - b No, only non-ferrous based materials can be inspected by DPI
 - c It is not specified in the TWI Specification regarding this material so I would accept
 - d No, Duplex and aluminum are acceptable but the material stated is unacceptable
- 9 In accordance with TWI Specification are the viewing conditions acceptable as stated in PT01
- a Acceptable if used for the TAM calibration
 - b Yes the conditions are acceptable
 - c No the conditions are not acceptable
 - d Acceptable when doing fluorescent
- 10 In accordance with the TWI Specification are the consumable manufacturers acceptable to the TWI specification
- a Yes, they are acceptable
 - b No, they are not acceptable
 - c The developer and penetrant only are acceptable to the specification
 - d The developer and remover only are acceptable to the specification

RT01 Questions

11 On Radiographic Inspection report RT 01, is the operator's qualification acceptable to the TWI specification?

- a Yes
- b No
- c This acceptable if the qualification to ISO 17636 has been verified
- d This is not acceptable because the level 2 is only a minimum

12 Is the material stated on RT 01?

- a Not permissible in the TWI specification
- b Not possible to radiograph due to its permeability
- c Not possible to radiograph due to its high density
- d Well suited to radiography and is acceptable to the TWI specification

13 Is the scope of inspection reported on RT 01 acceptable to the TWI specification?

- a If that's all that's accessible then yes
- b No
- c The specification only calls for 10% radiography on project 7690
- d All options are incorrect

14 In relation to the fixing conditions stated on RT 01

- a The time and temperatures stated are correct
- b The time is ok but the temperature is too high
- c The temperature is ok but the time is too long
- d All options are incorrect

15 In relation to the Development stated on RT 01

- a The time and temperatures stated are correct
- b The time is ok but the temperature is too low
- c The temperature is ok but the time is too long
- d All options are incorrect

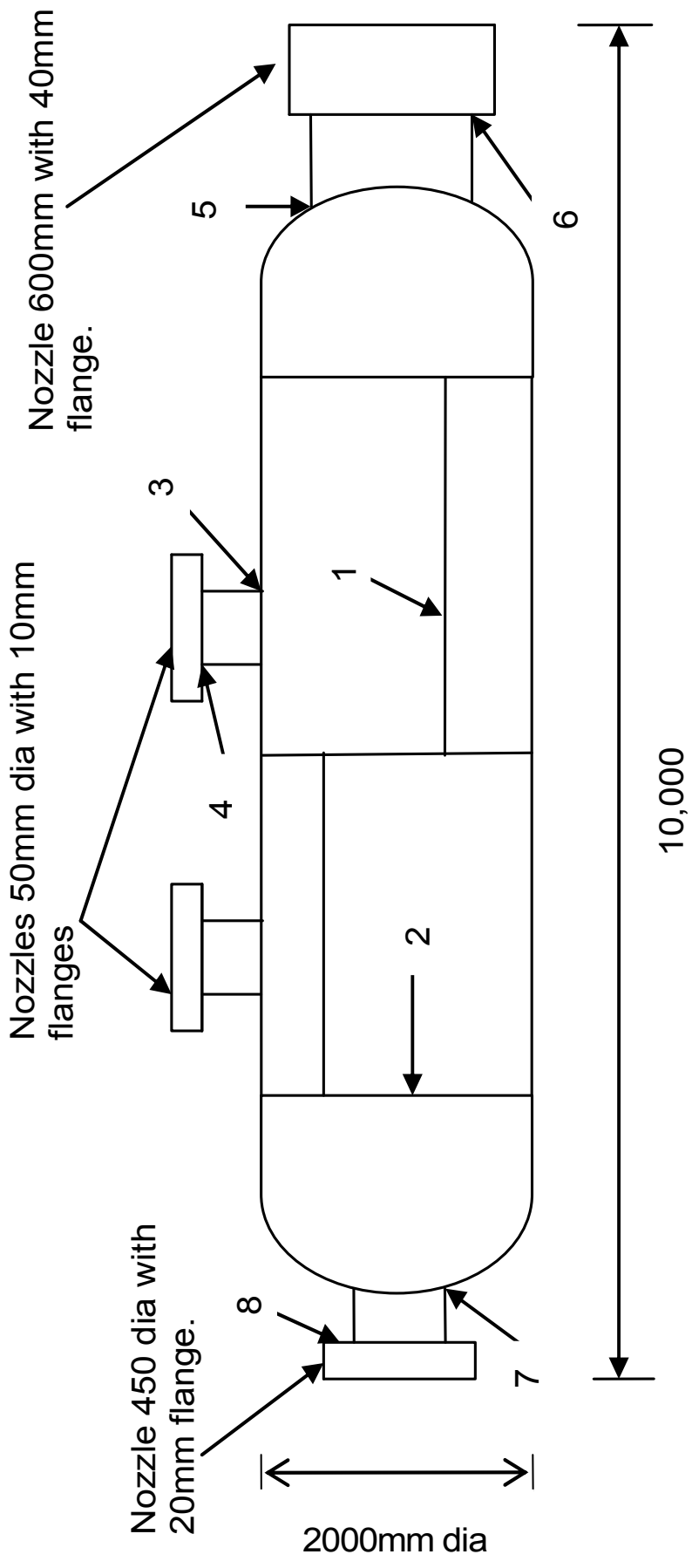
UT01 Questions

- 16 Do the calibration blocks shown on UT 01 comply with the requirements of the TWI specification?
- a The calibration blocks stated are specification compliant
 - b The blocks do not matter providing a resolution check is completed
 - c The calibration blocks stated are not specification compliant
 - d ONLY if a cross checker is present at calibration shall the specification allow the use of the V1,V2 blocks stated
- 17 Is it possible to use the 60 ° shear probe as reported in UT 01 to scan for the reported defect 1?
- a No
 - b Yes
 - c Only the crack like indication ,would be discovered
 - d It is possible if you scan at 40 ° to the probe angle itself
- 18 According to the TWI specification, Is the material stated on report UT 01 acceptable for ultrasonic examination
- a Yes it is acceptable to the specification with no special requirements.
 - b There is no mention of Aluminum in the specification
 - c Yes, ultrasonic testing is often used on Aluminum welds
 - d If the attenuation check is done then this material can be inspected by UT with company approval
- 19 In relation to the joint geometry stated on report UT 01
- a A 6 dB drop should be referenced here
 - b The report should state the bevel angle/included angle
 - c There would be sufficient information to conduct ultrasonic testing successfully
 - d A trained operator would know his beam path
- 20 How many probes would be used on a 25mm single V butt weld in accordance with the TWI specification?
- a Only a zero degree would be required for this joint
 - b 4 probes would be required
 - c 3 probes would be required
 - d All options are feasible if you have access to both sides of the joint

Appendix 3

Training Drawing

Drawing one CSWIP 3.2 weld symbols training



Appendix 4

Specification Questions

Senior Welding Inspector: Specification Questions

Name: Date:

1. The symbols s and $\leq$ refer to :-
 - a) Plate thickness and arrow side
 - b) Nominal throat thickness and less than
 - c) Nominal butt weld thickness and less than and equal to
 - d) Single sided and vee butt weld with reinforcement removed

2. In the case of a ferrous double sided butt weld, which inspection methods should be employed before the second side is welded.
 - a) Dye penetrant and MPI
 - b) Visual only under magnification of x5
 - c) Visual and dye penetrant
 - d) Visual and MPI

3. What would be the largest leg length dimensions and the smallest throat dimension of a fillet weld deposited on 12mm thick plates.
 - a) 12mm leg length, 8.4mm throat
 - b) 15mm leg length, 10.5mm throat
 - c) 14mm leg length, 9.8mm throat
 - d) 15mm leg length, 8.4mm throat

4. An arc strike has been removed by grinding and the inspection has proven acceptable. The thickness of the joint is 25mm and the removal depth 1mm deep. Is this acceptable?
 - a) There is no problem with 1mm as 2mm is acceptable
 - b) This is not acceptable as no reduction in thickness is allowed
 - c) Not acceptable as 0.5mm is the maximum reduction in thickness
 - d) As long as the inspection proved acceptable this would be allowable

5. Continuous Sub arc welding is being conducted on the manufacture of large I beams 15m in length. After completion of each I beam, the re cycled flux approximately 5kg in weight has another 5kg of new flux added before the operation continues again. Is this allowable?
 - a) No only new flux can be used
 - b) This is not required as the system has a filtration system built in
 - c) This combination of mixing new and used is adequate
 - d) It depends if the operation is hydrogen controlled or not

6. Ultrasonic testing of a circumferential pipe butt weld 200mm diameter and 25mm thick, has detected lack of fusion 180mm in length. The contractor has a repair procedure and wants to carry out a repair. What would be your course of action?
- a) If it's a first repair and the procedure is being followed, this would be allowable
 - b) If a qualified inspector witnessed the repair this would be allowable
 - c) You should not allow this to happen until you witness a repeat of the NDT
 - d) You should insist on a complete cut out
7. The following parameters were used on a 10mm thick austenitic stainless steel butt weld using the TIG process, 12 volts, 180 amps and a travel speed of 40mm per minute. Witnessing this operation, what would be your course of action?
- a) The heat input is too high so stop the operation
 - b) The heat input is too low so stop the operation
 - c) As long as the welding procedure is adhered to, continue the operation
 - d) No options are correct
8. A procedure was conducted in the PF position with MMA in 15mm thick C Mn steel. The following tests were conducted, hardness, macro, side bends, tensile, and impacts. Which of the following statements is correct?
- a) The procedure can be used in any position
 - b) The procedure can only be used in the original test position
 - c) The procedure can be used in the PA, PB, PC and PF positions
 - d) The procedure can be used in the PC, PF and PD positions
9. A quenched and tempered steel has to undergo Post Weld Heat Treatment. Which of the following is correct?
- a) Heating rate controlled from 320°C, soak temperature 590°C, cooling rate controlled to 320°C and thermocouples removed at 110°C
 - b) Heating rate controlled from 300°C, soak temperature 580°C, cooling rate controlled to 300°C and thermocouples removed below 110°C
 - c) Heating rate controlled from 220°C, soak temperature 450°C, cooling rate controlled to 220°C and removal of thermocouples at this point
 - d) Heating rate controlled to a soak temperature of 700°C, cooling rate controlled to ambient at which point thermocouples removed.
10. A quenched and tempered steel 40mm thick requires pre heating at a temperature of 100°C and a controlled interpass temperature of 100°C. the SAW process is being used. The heat input must be controlled. Which of the following conforms?
- a) 28 volts, 450 amps, travel speed 650mm per min
 - b) 32 volts, 650 amps, travel speed 400mm per min
 - c) 32 volts, 620 amps, travel speed 350 mm per min
 - d) 32 volts, 750 amps, travel speed 800 mm per min