WELDING INSPECTION - STEELS

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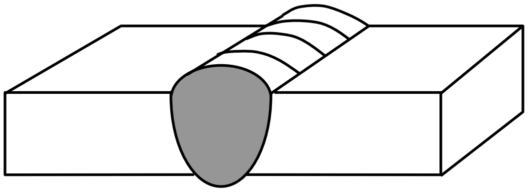
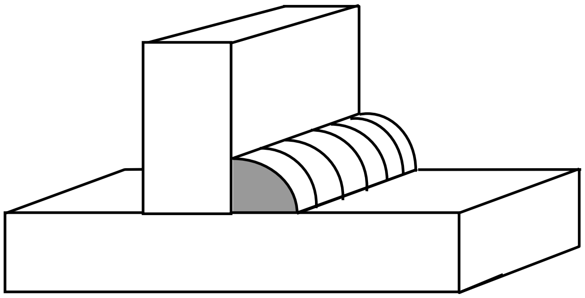
TERMINOLOGY

Use of the correct terminology is important. CSWIP uses BS 499 standard. Frequently the terms ‘weld’ and ‘joint’ are used incorrectly. Exact definitions are given in BS 499 PT 1 1983 - ‘Welding terminology’ and BS 499 Pt 2: 1980 ‘ Weld symbols’.

TYPES OF WELD

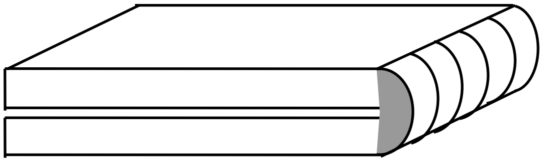
Butt Weld

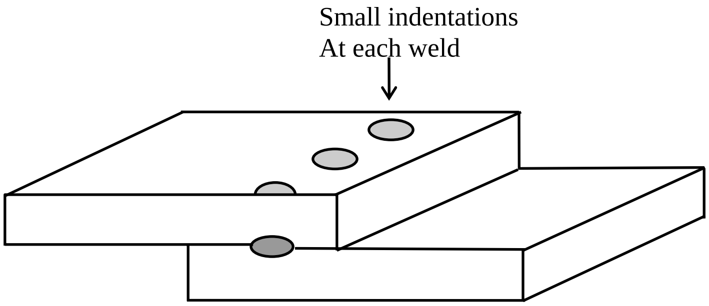




Fillet Weld

Edge Weld





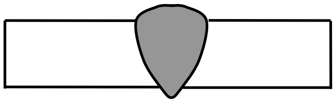
Spot Weld
(Illustration depicts resistance weld. Spot welds can be made with MIG or TIG processes.)

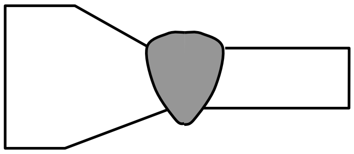
The four basic welds can be used to join various types of joints.

TYPES OF JOINT

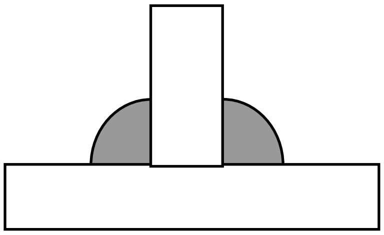
The following are some typical joints:

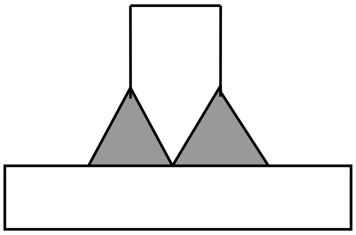
BUTT



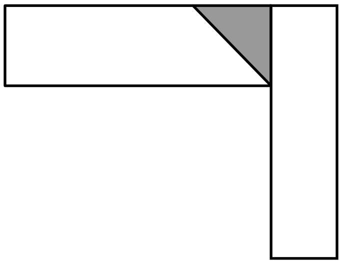


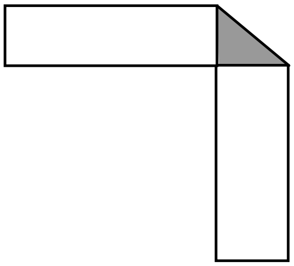
TEE





CORNER

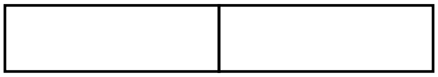




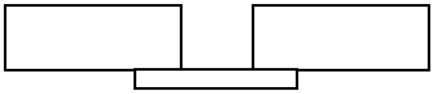
LAP

PLATE EDGE PREPARATION FOR BUTT WELDS

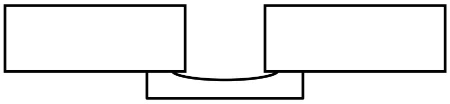
The illustrations show standard terminology for the various features of plate edge preparations.



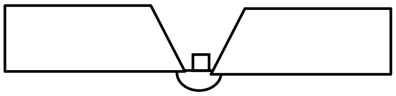
Square edged closed butt
< 3 mm – sheet, > 3 mm - plate



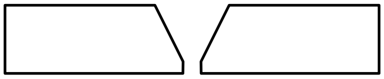
Square edged open butt with backing strip
(considerations - penetration control, backing strip of the same material and usually removed)



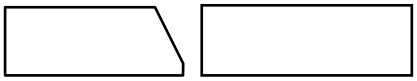
Backing bar - ceramic or copper
(copper can cause loquation cracking)



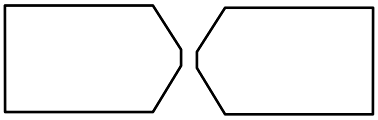
Fusible insert - electric bolt (e.b)
(Uses TIG process)



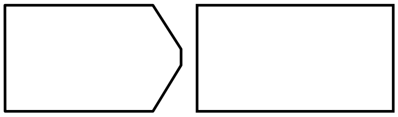
Single V



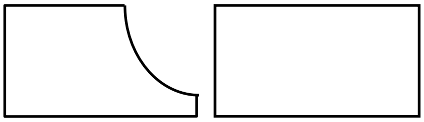
Single bevel



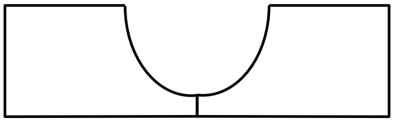
Double V



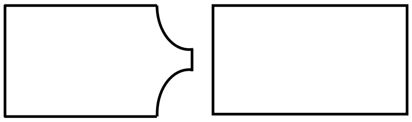
Double bevel



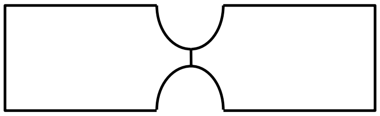
Single J



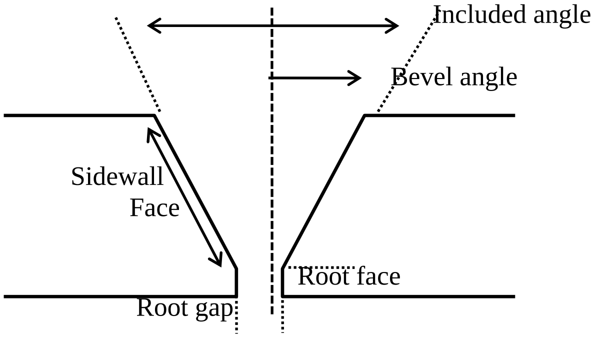
Single U

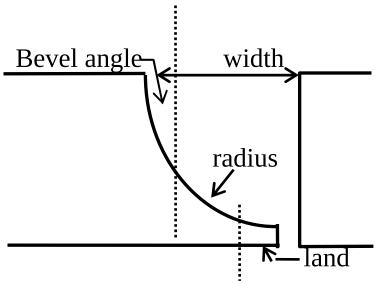


Double J



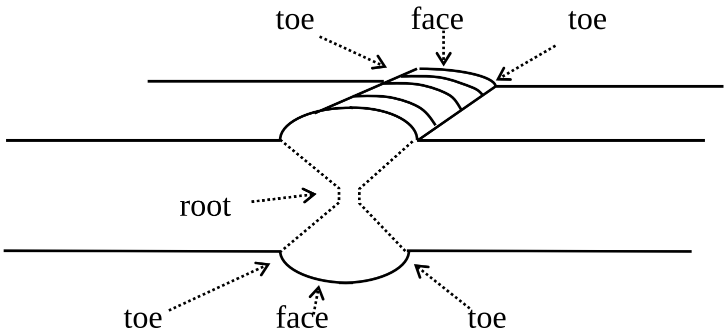
Double U



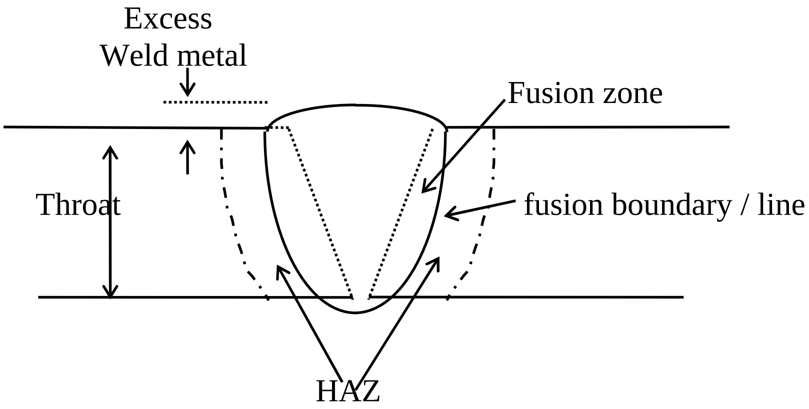


FEATURES OF A COMPLETED WELD

A butt weld in plate, made by welding from both sides, has two weld faces and four toes. In a full penetration weld made from one side, the protruding weld on the underside is called the penetration bead, which also has two toes. The root is defined (BS 499) as the zone on the side of the first run farthest from the welder.

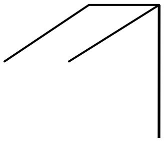


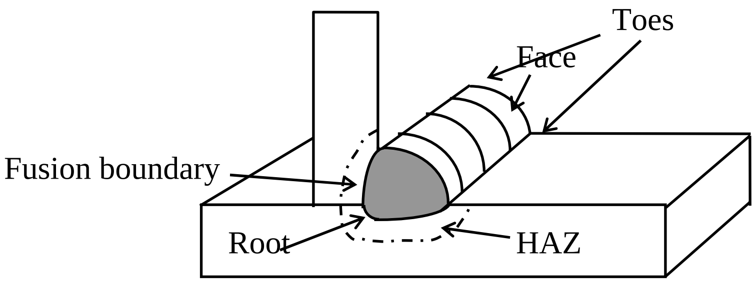
If a weld is sectioned, polished and etched, the fusion boundary can be established. Metal lying between the two fusion boundaries is weld metal - a mixture of deposited metal and plate metal that has been melted. The fusion zone is the area of highest dilution between filler metal and parent plate. Adjacent to the fusion boundary is the heat affected zone (HAZ), in which the plate material has had its metallurgical structure modified by the heat of welding.



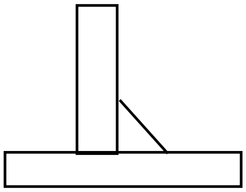
Excess weld metal is the correct term, not ‘weld reinforcement’. Excess weld metal lying outside the plane joining the toes of the weld.

Fillet welds have similar features.

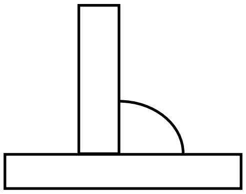




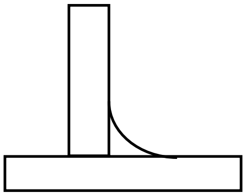
The shape of a fillet in cross-section is described in three terms.



Mitre fillet



Convex fillet



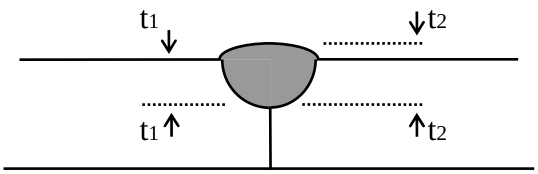
Concave fillet

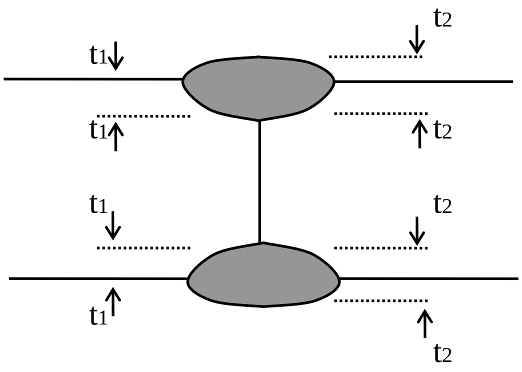
A convex fillet has a poor toe blend - greater notch effect and sharper angle at toe, not used in fatigue situations. A concave fillet has a better toe blend for fatigue situations, however a reduced throat. The concave weld may be made by welding alone or by subsequent grinding.

SIZE OF WELDS

Full Penetration Butt Welds.
The general rules are: design throat thickness = thickness of the thinner part joined.
Cap width = prep width + 10% either side (for open prep, not specified in BS 499)

Partial Penetration Butt Welds.
The term partial penetration strictly implies butt welds that are designed to have less than full penetration. Failure to achieve full penetration when it is wanted should be listed as the defect incomplete penetration.
The design throat thickness of a partial penetration weld is t_1 and the actual throat thickness is t_2. With a partial penetration weld made from both sides, the design throat thickness is $t_1 + t_1$ and the actual throat thickness is $t_2 + t_2$. Note that the degree of penetration must be known.





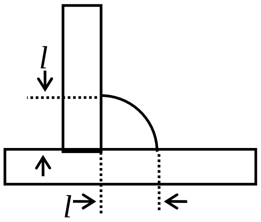
Fillet Welds.

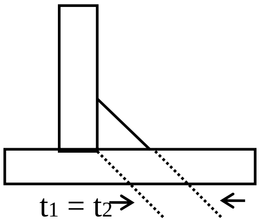
Fillet weld sizes are calculated by reference to allowable shear stress on the throat area, i.e.

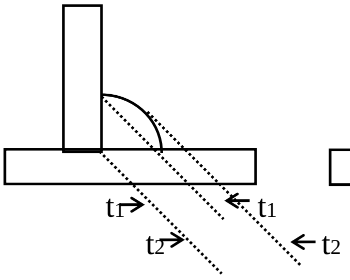
Throat area = design throat thickness x length of weld.

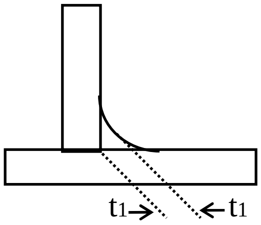
The size required is specified on drawings in terms of leg length (*l*).

For fillet welds with equal leg lengths $l = 1.4\ t_1$. This does not apply to concave fillet welds.

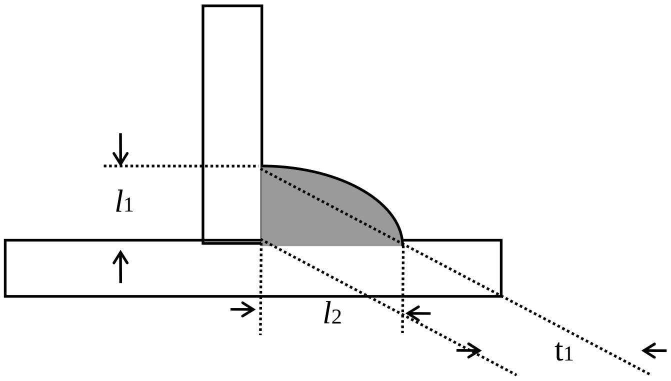






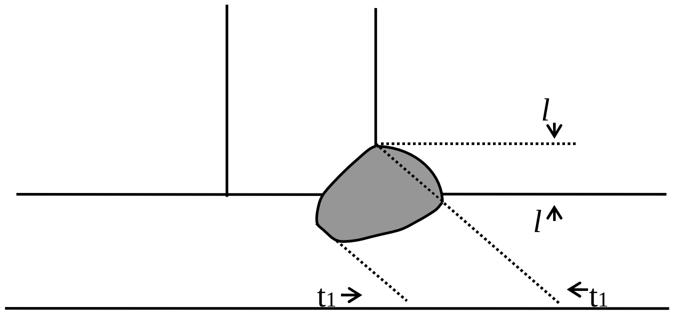


If an asymmetrical weld is required, both leg lengths are specified and t_1 is taken as the minimum throat dimension.



Deep penetration fillet weld.

With high current density processes, e.g. submerged arc and MIG (spray), penetration along the joint line can be produced. This gives an increase in throat thickness with no change in leg length.



VISUAL INSPECTION

At any point in the course of welding, i.e. tacking, root pass, filler pass or capping pass, but particularly for the root and cap, a detailed inspection may be required. British Standard 5289: 1976 gives guidance on tools and responsibilities together with sketches of typical defects.
The inspector at this point must -

a) Observe, identify and perhaps record (measure) the features of the weld.
b) Decide whether the weld is acceptable in terms of the particular levels that are permitted; defect levels may be 'in-house' or national codes of practice.

When the defect size is in excess of the permitted level then either a concession must be applied for (from a competent person), or the weld rejected.

AIDS OF VISUAL INSPECTION

Illumination: Good lighting is essential.
Inspection Lenses: The magnification should not exceed 2 - 2.5 diameters. If higher magnification is required use a binocular microscope.
Optical viewing can progressively develop from eyesight, to use of a hand torch and mirror, to the addition of a magnifier and light source.
In order to achieve accessibility, remote probe units are available which must have the following properties.

a) Large field of vision
b) Freedom from distortion of image
c) Accurate preservation of colour values
d) Adequacy of illumination

CODE OF PRACTICE

A code of practice for an inspection department should take the form outlined below. It is appreciated that full implementation of the code would be extremely costly and therefore it may be necessary to reduce the amount of inspection to less than is theoretically required.
The inspector should be familiar with the following:

a) All applicable documents
b) Workmanship standards
c) All phases of good workshop practice
d) Tools and measuring devices

INSPECTION BEFORE WELDING

Before Assembly:
Check * All applicable documents.
* Quality plan is authorised and endorsed with signature, date and company stamp.
* Application standard is up to date with the latest edition, revision or amendment.
* The drawings are clear, the issue number is marked and the latest revision is used.
* Welding procedure sheets (specifications) are available, have been approved and are employed in production.
* Welder qualifications with identification and range of approval are verified and that only approved welders as required are employed in production.

* Calibration certificates, material certificates (mill sheets) and consumer certificates are available and valid.
* Parent material identification is verified against documentation and markings.
* Material composition, type and condition.
* Correct methods are applied for cutting and machining.
* Identification of welding consumables such as electrodes, filler wire, fluxes, shielding and backing gases and any special requirements (e.g. drying) are met.
* Plant and equipment are in a safe condition and adequate for the job.
* Safety permits e.g. hot work permit, gas free permit, enclosed space certificate are available and valid.

After Assembly

Check * Dimensions, tolerances, preparation, fit-up and alignment are in accordance with the Approved drawings and standards.
* Tack welds, bridging pieces, clamping and type of backing - if any used are correct.
* Cleanliness of work area is maintained.
* Preheat in accordance with procedure.

NOTE Good inspection prior to welding can eliminate conditions that lead to the formation of defects.

INSPECTION DURING WELDING

Check * the welding process must be monitored.
* Preheat and interpass temperatures must be monitored.
* Interpass cleaning - chipping, grinding, gouging, must be monitored.
* Root and subsequent run sequence.
* Essential variables such as current, voltage, travel speed to be monitored.
* Filler metals, fluxes and shielding gases are correct.
* Welding is in compliance with weld procedure sheet and application standard.

INSPECTION AFTER WELDING

Check * Visual inspection to be carried out to ascertain acceptability of appearance of welds.
* Dimensional accuracy to be ascertained.
* Conformity with drawings and standards requirements.
* Post weld heat treatment, if any, monitored and recorded.
* NDT carried out and reports assessed.
* Assess defects as to either repairing, or application for concession.
* Carry out any necessary repairs.
* Control of distortion

REPAIRS

* Repair procedure and welding code should be authorised.
* Defect area should be marked positively and clearly.
* Check when partially removed and fully removed (visual and NDT).
* Re-welding should be monitored.
* Re-inspect completed repair.

Collate all documents and reports. Pass the document package on to a higher authority for final inspection, approval and storage.

THE WELDING INSPECTOR

RESPONSIBILITIES

Ensure compliance with standard or code.
Ensure workmanship.
Ensure welding criteria by ‘policing’ work and documentation.

ATTRIBUTES

Honesty and integrity.
Literacy.
Fitness - physical and eyesight.

DUTIES

Observe.
Measure.
Identify.

CODES AND STANDARDS

CLASS OF WORK

There are many types of work which require engineering materials to be joined by welding, for example:

Pressure vessels
Oil rigs
Aero-engines
Storage tanks
Car bodies
Bridges
Earth moving equipment
Ventilation systems
Heavy vehicle chassis
Food processing plant

The quality requirements of the joints in these fabrications depend on their fitness-for-purpose and differ significantly from one application to the next. Pressure vessels require welds, which can withstand the stresses and high temperatures experienced in operation. Oilrigs are designed to withstand the effect of wave formation and wind loads. Earth moving equipment has to accommodate differences in terrain and earth conditions and is subject to fatigue loading. Welds in food processing plants must withstand corrosion by hot acidic liquors.

Below are listed some typical codes of practice and standards which cover various types of constructions fabricated by welding.

Code	Class of Work
BS 5500	Unfired fusion welded pressure vessels
ASME VIII	American boiler and pressure vessel code
BS 2633	Class 1 arc welding of ferritic steel pipe work for carrying fluids
BS 4515	Process of welding steel pipelines on land and offshore
BS 5950	Structural use of steelwork in building
AWS D1.1	Structural welding code (American)
BS 5400	Steel, concrete and composite bridges
BS 6235	Code of practice for fixed offshore structure
API 1104	Standard for welding pipelines and related structures

These documents can also provide a useful source of data for applications where codes do not exist. It should be remembered, however, that the principal criterion in the codes listed is the quality of the joint in relation to the service conditions. There are other applications where success is judged by different criteria, such as dimensional accuracy.

Another important consideration is controlling the cost of welding. Variations in weld times and quantities of consumables can readily result if the method of making a weld is left to the welder to decide.

The continuous and satisfactory performance of weldments made to various codes requires that specific guidelines are laid down to cover all variables. These guidelines are usually grouped under the general heading of a Weld Procedure.

CODE OF PRACTICE

A code of practice is a set of rules for manufacturing a specific product. It should contain:

Design Requirements	e.g. fit-up, preparation and type of joints
Materials	e.g. types, thickness ranges
Manufacturer's Working Practice	
Inspection Criteria	e.g. 100% visual, percentage other NDT
Acceptance Criteria	e.g. defect size, limits, etc.
Welding Process	e.g. type, consumables

Types of Tooling	e.g. use of strong backs
Contractual Information	

The difference between a code and a standard is that a code states how to do a specific job and does not contain all relevant information, but refers to other standards for details.
A code or standard generally mentions three parties - the customer or client, the manufacturer or producer and the inspection authority. In a code the term ‘shall’ means mandatory - must be done, and the term ‘should’ means recommended - not compulsory.
A concession is an agreement between the contracting parties to deviate from the original code requirements. (BS 5135)

THE WELDING PROCEDURE

A welding procedure is a way of controlling the welding operation.

Purpose of procedure:

1) To prove a joint can meet design procedure - *consistency*
2) Instruction for welder
3) Ensure *repeatability*

Weld procedures are approved to ensure they are functional and fulfil the physical and mechanical properties necessary to reach the required standard (to establish the essential variables for contractual obligations).

Welders are approved to ensure a particular welder is capable of welding to a procedure and obtaining a result that meets specification.

The task of collecting the data and drafting the documentation is often referred to as ‘writing’ a weld procedure. In many ways this is an unfortunate term as the writing of documents is the last in a sequence of tasks.

Producing a weld procedure involves;

Planning the tasks
Collecting the data
Writing a procedure for use or for trial
Making test welds
Evaluating the results of the tests
Approving the procedure of the relevant code
Preparing the documentation

In each code reference is made to how the procedures are to be devised and whether approval of these procedures is required. In most codes approval is mandatory and tests to confirm the skill of the welder are specified. Details are also given of acceptance criteria for the finished joint.

The approach used depends on the code, for example:
BS 2633 (Class 1 arc welding of ferritic steel pipe work for carrying fluids) provides general comments on various aspects of a suitable weld procedure.
AWS D.1.1 (Structural welding code - steel) favours more specific instructions for different joints and processes that are, in effect, pre-qualified procedures.
Other codes do not deal specifically with the details of the weld procedure but refer to published documentation, e.g. BS 5135 ‘process of arc welding carbon and carbon manganese steels’.

COMPONENTS OF A WELD PROCEDURE

Items to be included in the procedure can be some of the following:

Parent Metal
  a. Type
  b. Thickness (for pipe this includes outside diameter)
  c. Surface condition
  d. Identifying marks
Welding Process
  a. Type of process (MMA, TIG, SAW etc.)
  b. Equipment

- c. Make, brand, type of welding consumables
- d. When appropriate, the temperature and time adopted for drying and baking of electrodes And / or consumables

Joint Design

- a. Welding position
- b. Edge preparation
- c. Method of cleaning, degreasing etc.
- d. Fit up of joint
- e. Jigging or tacking procedure
- f. Type of backing

Welding Position

- a. Whether shop or site weld
- b. Arrangement of runs and weld sequence
- c. Filler material, composition and size (diameter)
- d. Welding variables - voltage, current, travel speed
- e. Weld size
- f. Back gouging
- g. Any specific features, e.g. heat input control, run-out length

Thermal Treatment

- a. Preheat and interpass temperatures including method and control
- b. Post weld treatment including method and control

ESSENTIAL VARIABLES

An essential variable is a variable that will influence or change the mechanical or metallurgical properties of the welded joint - changes affecting the procedure approval. Any change in an essential variable requires a new welding procedure specification (WPS).
Essential variables include: wall thickness, joint design, process, materials, consumables, welding position, direction, heat input (voltage, amperage, and travel speed), heat treatment.

APPROVING THE PROCEDURE

When the data has been collected, the procedure must be validated by producing and testing a trail weld.
If the procedure is to be used on a fabrication, which has been designed to meet the requirements of a code, the test weld is done under the supervision of an independent witness. The detailed arrangements for the test are subject to agreement between the contracting parties.
A number of British Standards make cross-reference to another standard which covers approval testing. Other codes of practice include their own weld procedure / welder approval information. In general they include a standard format, which can be used to report the results of an approval test.

Range of approval. (Extent of approval, scope of approval)
Provides a working range over which certain variables may alter without requiring a new welding procedure or welder approval.
Variables include thickness (e.g. 1/2 down to 2x above), diameter (e.g. 1/2 down to 1/2 above) materials (different materials can be covered), position, process, parent plate group, and consumables.

Re-approval of a welding procedure is necessary if there is a change of any of the essential variables or considerable defect re-occurrence.

ABBREVIATIONS

WPS	welding procedure specification - an approved and accepted welding procedure; an authorised document.
PQR	procedure qualification records - proof the procedure works - record of tests undertaken to qualify procedure.
WAC	welder approval certificate - required to ensure a particular welder is capable of welding to a procedure.
WATC	welder approval test certificate.
WAR	welder approval record.
WPAR	welding procedure approval record.
WQT	welder qualification test.
pWPS	preliminary WPS - unauthorised (contains all essential variables and, after welding the test piece and all NDT and destructive tests have been accepted, then the WPS can be approved).

pWPS and WPAR give final WPS (various WPS can derive from one pWPS).

DOCUMENTATION

The objectives of a procedure or welder approval test are:
a. to prove the procedure meets the necessary requirements with reference to feasibility, mechanical strength etc.
b. to prove the welders are competent to work on a particular job.
If a customer queries it, evidence can and would be supplied to prove validity.

Approval Test Specifications call for a paper record, which can be known as:
Procedure / welder approval certificate
Procedure / welder approval record
Procedure / welder approval report
The following records should also be kept:
NDT reports
Records of visual examination or mechanical testing
Test pieces from destructive testing
Other records that are equally important are *proof* of regular employment on a job for scheduling re-tests to avoid duplication on procedure approval.

WELDER APPROVAL

Welder approval tests are used to determine the ability of a welder to produce welds of an acceptable quality with the processes, materials and welding positions that are to be used in production. Dependant on the requirements and administration the manufacturer or contractor may choose to qualify their own welders or they may employ outside personnel who can meet the requirements. These requirements usually specify verification of the tests by an authorised inspector or independent body. The requirements for the qualification of welders are usually laid down in the governing code or specification or the contract specification.

Approval tests improve the probability of obtaining satisfactory welds in production. However it is true to say that approval test welds are made with special attention and effort and so cannot show whether or not the welder can do so under every production condition. For these reasons complete reliance should not be placed on these qualifications - production welds should be inspected regularly to ensure that the standard is being kept up.

Types of Approval Tests.

Tests that are prescribed by most codes and standards are in the main similar. Common tests are:

a. Plate and structural members.
b. Pipe welding.
c. Positions of welding.
d. Testing of approval test pieces.
e. Re-tests.

a. Plate and structural members.

The requirements for welders of plate and structural parts (including pressure vessels) usually require the welder to make one or more test welds on plate or pipe assemblies with the qualified welding procedure. Each weld is tested in a specific manner, often both destructively and non-destructively. The requirements normally state the applicability of material thickness and welding positions that will qualify for production work. Other details will cover joint type and direction of welding when depositing vertical welds (vertically up or vertically down).

b. Pipe welding.

The requirements for the approval of welders for pipe welding differs from those for welding plate and structural members chiefly in the type of test assemblies and test positions. As a rule the welds must be made on pipe and not plate. In some cases the space within which the test piece must be welded may be restricted if the production work involves welding in cramped conditions. As general rule welders who qualify for certain joints on pipe need not qualify for plate work, but qualifications on plate do not apply to pipe work.

c. Position of welding.

Approval tests are normally expected to be made in the most difficult positions that will be encountered in production welding. For example qualification in the vertical, horizontal and overhead positions usually qualifies for welding in the flat position.

d. Testing of welder approval test pieces.

All codes and specifications will have definite rules for the testing of approval welds to determine compliance. Most frequently this involves the removal of specimens for mechanical tests, such as bend tests, and specimens for macro examination from specific locations in the test pieces. Non-destructive testing may be required in conjunction with the mechanical tests.

Other properties required of the procedure qualification welds such as tensile strength, hardness, etc. are not generally specified in welder approval tests since these properties depend primarily on the parent and filler materials used on procedure details that are beyond the individual welder's control.

Welders whose test welds meet the requirements are qualified to use the process and to weld with the filler metals and procedures similar to those used in testing. It should be mentioned that a welder who has successfully welded a procedure test specimen is not required to undergo an approval test, unless the requirements of production welding are different from those of the procedure in which he has qualified.

e. Re-tests.

The circumstances for the re-testing of a welder include the following:

1. Failure of the initial test welds.
2. A significant change in welding procedure.
3. A welder has not been engaged in welding for an extended period. (Usually three months.)
4. There is reason to question the welder's ability.
5. Change of employment without the transfer of his approval certificates.

CHECK LIST FOR WELDER AND PROCEDURE APPROVAL

1. The test being carried out is the correct one required.
2. Welders are in possession of all relevant information concerning the test.
3. Test materials confirm in all respects to requirements.
4. Joint configuration and tolerances are correct.
5. Welding plant and consumables.
6. The welder's identification is clearly marked on the test piece.
7. Where it is specified for a root run to be stopped and restarted in a certain position, that this Position is clearly marked.
8. In the case of joints welded in fixed positions the test piece is so fixed that it cannot be moved.
9. All ancillary tools such as chipping hammers, wire brushes, grinders, etc. are available.

The tests should be carried out without interruption but with sufficient supervision to ensure that the requirements are being complied with. Where welder approval is carried out in accordance with ASME section IX it states that the person supervising the test may, if in his opinion he considers that the welder will not meet the required standard, terminate the test at any time. If it is necessary to apply this ruling, it is suggested that full reasons for termination be recorded. It is further recommended that the test piece should also be kept for a short period as a means of backing up written statement.

If the test is to be supervised by a representative of an independent authority he should be given all the relevant details of the testing required.

Where British standards are involved, they generally state that if the welder is of the opinion that his first attempt may not pass any subsequent testing, he may withhold it and weld a second. In this case it is the second test piece that is submitted for examination and the first one must be scrapped.

TEST CERTIFICATE

Should state clearly that it is a welder approval and not a procedure approval, and, depending on the particular standard, should contain the following:

a. welder’s name and identity number
b. date of test
c. standard of code in full, e.g. British Standard 4872 PT 1: 1982
d. test piece details including material specification
e. equipment and consumable details
f. extent of approval
g. sketch of run sequence, preparation and dimensions
h. other factors, operating parameters etc.
i. the test results (visual, NDT, DT etc.)
j. remarks
k. witnessed by
l. test supervisor
m. location

Most standards give an example of a test certificate.

Signatures on certificates must be endorsed by company stamp.

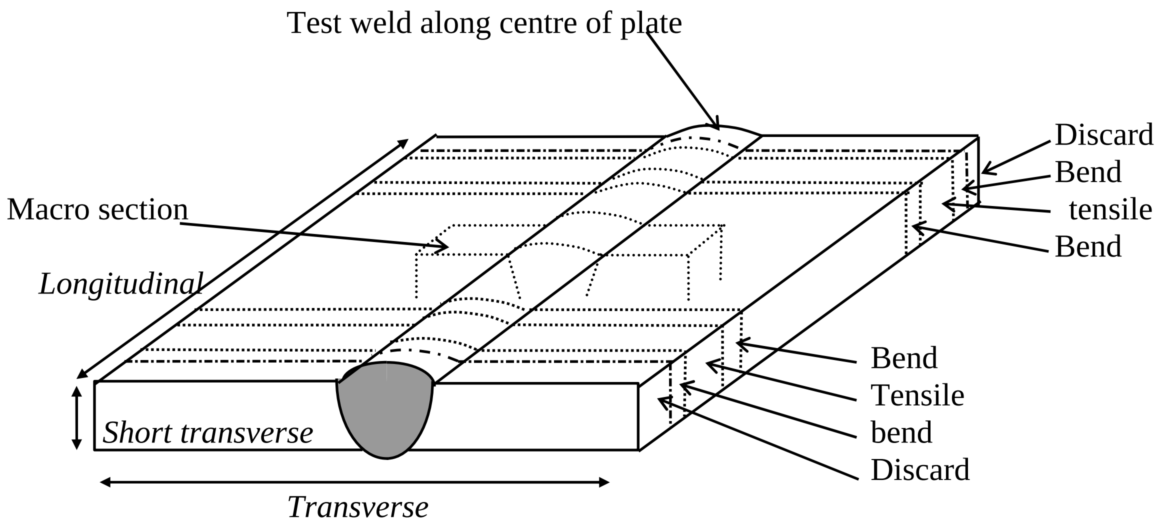
DESTRUCTIVE TESTING

Destructive tests on welded joints are usually made as part of the approval of a welding procedure or a welder.

Commonly used destructive tests are:

Bend
Tensile
Charpy
Fracture tests
Macro section

The test pieces are cut from the test weld and their location is often specified in the standard. The British standard for the testing of welds is BS 709: 1983 Methods of testing fusion welded joints and weld metal in steel. The areas for test are shown below.



BEND TESTS

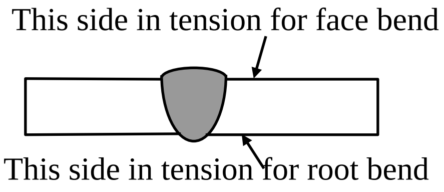
Object:	To determine the soundness of weld metal, heat affected zone and weld zone. These tests may also be used to give some measure of the ductility of the weld zone. It is not usual to use transverse and longitudinal bend tests for the same application.
Method:	All specimens to be removed and prepared without causing significant distortion or heating. The cap and root are ground flush. The specimen is bent by the movement of a former of prescribed diameter, the relevant side of the specimen to be placed in tension. Angle of bend and diameter of former should be as specified in the appropriate standard.

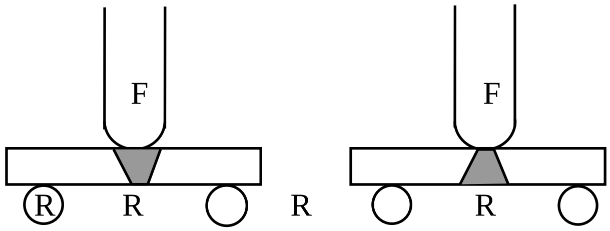
Reporting Results:

1. Thickness of specimen
2. Direction of bend (root or face)
3. Angle of bend
4. Diameter of former
5. Appearance of joint after bending e.g. type and location of flaws

Root bend
Force ↓

face bend
force ↓





Surface in contact with former ground flat. .R = roller support F = former of specified radius

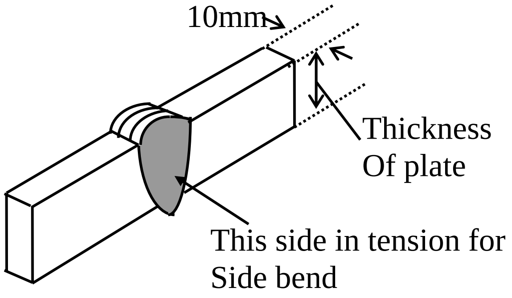
SIDE BEND TEST

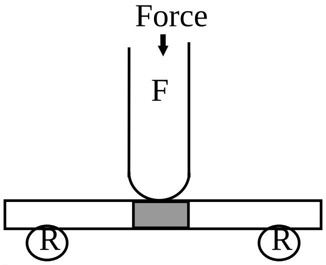
Object: To determine the soundness of the weld metal and HAZ in a cross section. This may be preferred to the transverse bend test on thick materials. It is also used on processes or procedures expecting lack of fusion (e.g. thick plate using MIG).

Method: The testing method is the same as that used for transverse bends except the cap and root is not ground flush, to allow testing across the complete weld.

Report Results:

1. Width and thickness of specimen.
2. Angle of bend.
3. Diameter of former.
4. Appearance of joint after bending e.g. type and location of flaws.





R = roller support
F = former of specified radius

TRANSVERSE TENSILE TEST

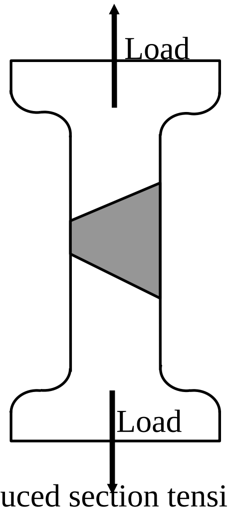
Object: Used to measure the transverse tensile strength under static loading of a butt joint employing butt welds.
The reduced section tensile test normally fails in the parent metal and so it is not designed to give the tensile strength of the weld.
The radius reduced tensile test is a test of the as deposited diluted weld metal.
The all weld tensile test, using a longitudinal section from the weld only, is used to check the as deposited undiluted weld metal. (Usually used by consumable manufacturers.)

Method: The test piece is clamped at each end and a load is applied by a hydraulic or screw Mechanism. The load is increased until fracture occurs.

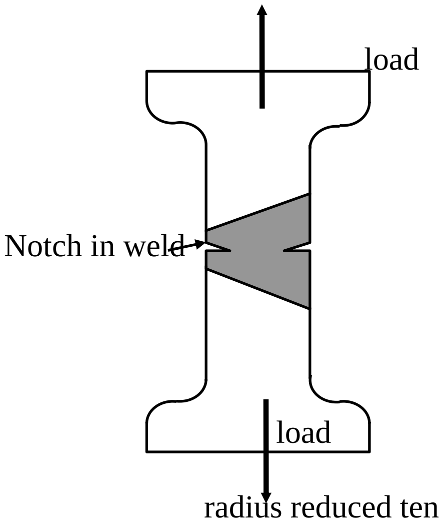
Reporting Results:

1. Type of specimen (e.g. reduced section).

2. Whether excess weld metal is removed or not.
3. Tensile strength, in Newton's per mm squared, is calculated from maximum load and original cross sectional area. When excess weld metal is not removed, the cross sectional area shall be the product of the parent metal thickness and the width of the specimen.
4. Location of fracture - whether in parent plate, heat affected zone or weld metal. If the fracture is in the parent metal, the distance from the weld zone shall be stated.
5. Location and type of any flaws present on the fracture surface.

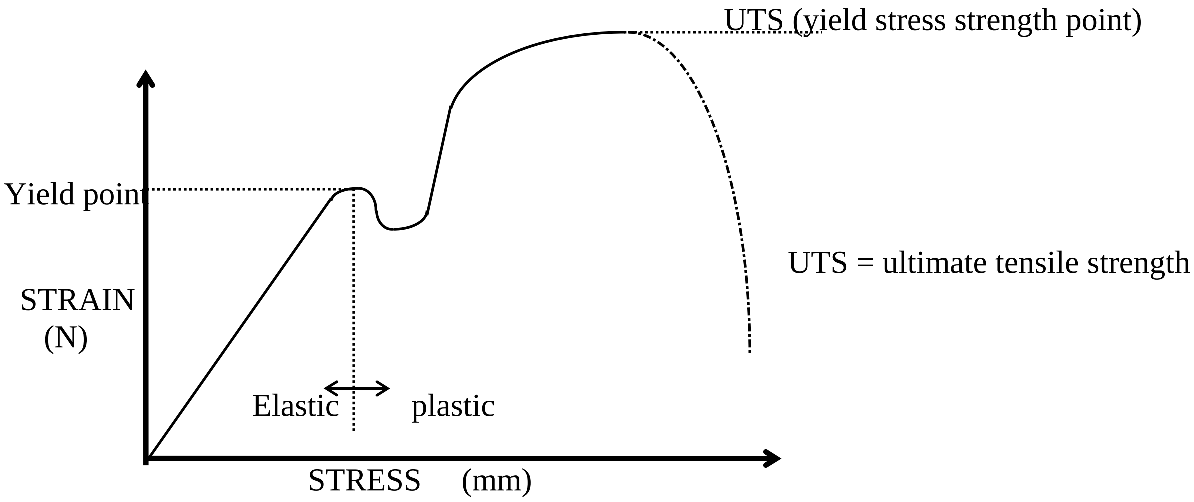


Reduced section tensile test



radius reduced tensile test

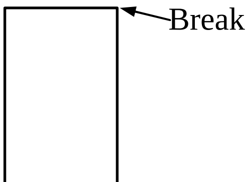
The test gives a measure of percentage elongation, percentage reduction in area and ultimate tensile Strength.

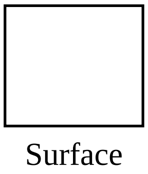


The tensile test gives a measure of DUCTILITY.
(In Newton's per mm squared a combination of percentage elongation and percentage reduction in area.

Types of failures.

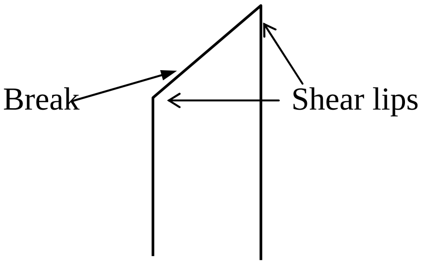
BRITTLE

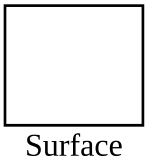




Brittle fracture is flat and featureless.

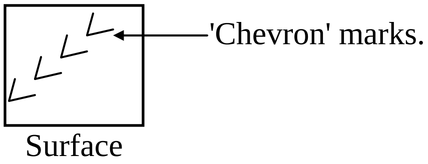
DUCTILE





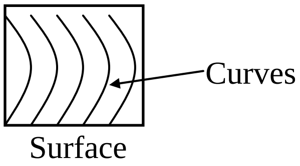
A ductile fracture tears at 45° to the load.

IN-SERVICE BRITTLE FRACTURE



A flat surface with chevron markings that point to the material defect that initiated the fracture.

FATIGUE FAILURE



A flat surface with noticeable curves.

CHARPY V NOTCH IMPACT TEST

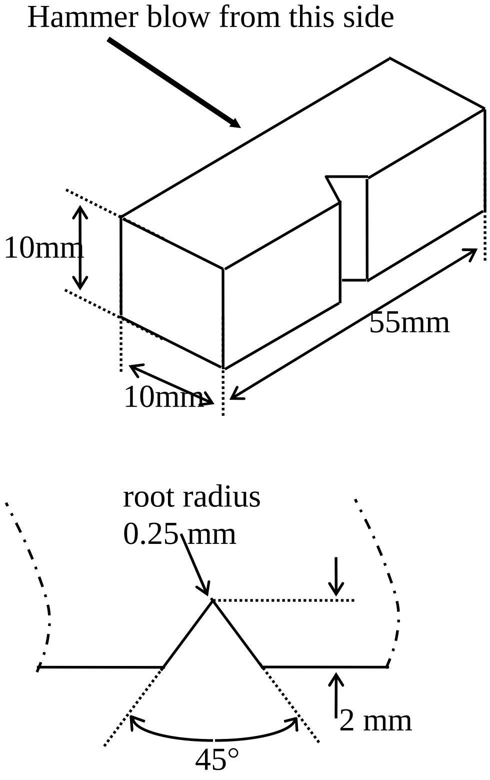
Object: To determine the amount of energy absorbed in fracturing a standardised testpiece at a specified temperature.

Method: A machined, notched specimen is broken by one blow from a pendulum. Because scatter occurs in the results, at least three specimens are used to assess the joint represented.
Testing is carried out at a temperature specified in the appropriate application standard.
The British standard is BS 131: PT 2: 1972.

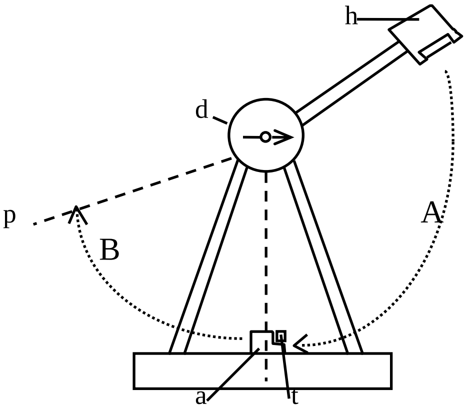
Reporting Results:

1. Location and orientation of the notch.
2. Testing temperature.

3. Energy absorbed in joules.
4. Description of fracture appearance.
5. Location of any defects.



CHARPY TEST PIECE



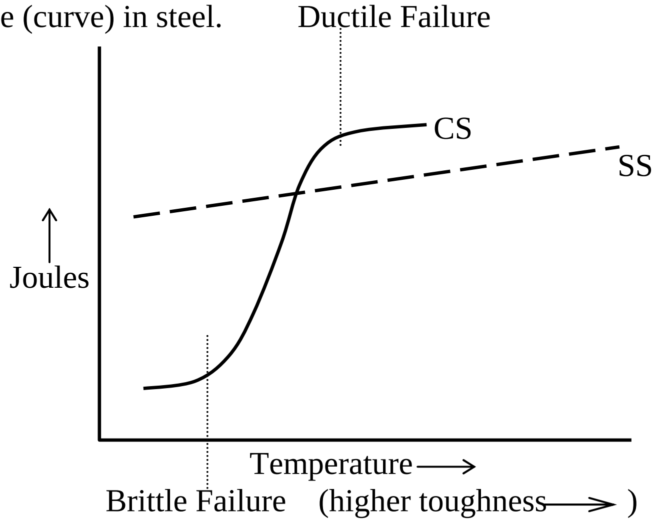
a - anvil
t - test piece
h - Hammer
d - Dial calibrated in joules
p - Point reached after fracture

Energy absorbed during fracture is proportional to (A - B)

CHARPY IMPACT MACHINE

The Charpy impact test, measured in joules, is an assessment of TOUGHNESS.

Transition temperature (curve) in steel.



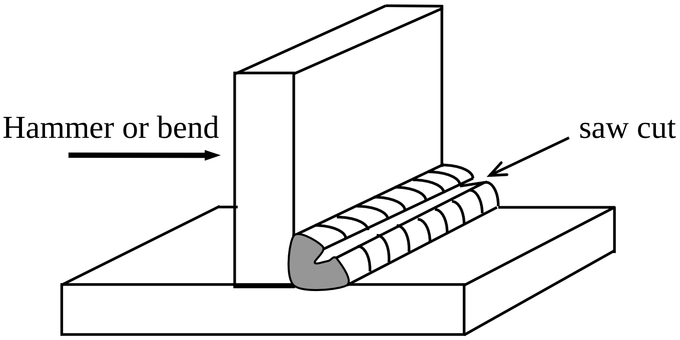
FILLET WELD FRACTURE TEST

Object: To break the joint through the weld to permit examination of the fracture surfaces for flaws and to check root penetration and fusion.

Method: The specimen is cut to length and a saw cut, normally 2 mm deep, is made along the centre of the weld face. The specimen is fractured by bending or hammer blows.

Reporting Results:

1. Thickness of parent material.
2. Throat thickness and leg length.
3. Location of fracture.
4. Appearance of joint after fracture.
5. Depth of penetration / lack of penetration or fusion.



‘NICK’ BREAK (BEND) TEST

Object: As for fillet weld fracture, used on butt welds.

Method: The specimen is cut transversely to the weld, and a saw cut is applied along the centre of the weld face. The best place for the cut is at a start / stop. The specimen is fractured by bending or by hammer blows. The nick bend test will find internal defects.

Reporting Results:

1. Thickness of material.
2. Width of specimen.
3. Location of fracture.
4. Appearance of joint after fracture.

MACRO SECTION

Object: To examine a cross section of a weld for internal defects and soundness.

Method: A transverse section of the weld is cut out. The cross section is then visually inspected. The section is filed down from rough to smooth, then emery or wet/dry papered down to a surface finish of 600 grit. The surface is then etched in NITAL (5% - 10% nitric acid in alcohol), washed off, rinsed and dried. (Possibly a final clean with acetone and mount in Bakelite.) The specimen is then inspected at up to 10-x magnification.

Reporting Results:

1. Material.
2. Welding process.
3. Specimen identification.
4. Sentencing standard.
5. Thickness.
6. Geometric flaws - type, size and location.
7. Internal flaws - type, size and location.
8. Parent metal flaws - type, size and location.
9. Accept or reject, to standard, for each flaw.

Comparison of macro section and micro section:

	MACRO	MICRO
Magnification	X 10	X 1000
Finish	600 grit	1 micron (high level polish)
Features/defects	cracks, slag, LOF, etc.	intergranular structure
Uses	procedure/welder qualification	research/failure analysis

TYPES OF TEST

Quantitative (measurable)	Qualitative
Tensile	Bend test
Charpy	Nick breaks
Hardness	Macro
C.T.O.T. (crack tip opening test)	Fillet fracture

SYMBOLS

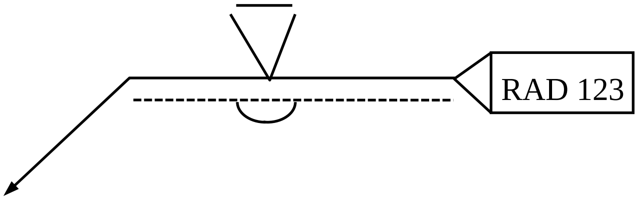
WELD SPECIFICATIONS

Welds must be specified by clear instructions and all staff including production personnel must understand the weld symbols specified.
It may be necessary to specify more details about the weld e.g. size, or electrode to be used, or even the full details of a weld procedure may be needed.
The methods most commonly used to specify a weld are:

Written statement.

Weld XYZ is to be a single V butt welded from the outside of the vessel. The surface of the weld is to be ground flush. The root is to be sealed with a weld run deposited from inside the vessel. The completed weld is to be radiographed.

Symbols on a drawing:



Both the above give the same information.

Standards for weld symbols:

Although the main features of weld symbols are international, variations in detail occur from country to country. Symbols are specified by national standards.

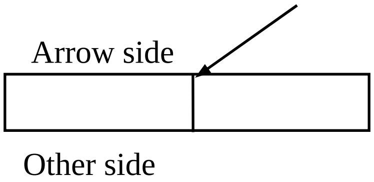
UK.................................BSEN 22553
USA...............................AWS 2.4

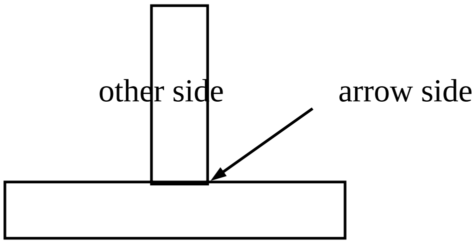
In this text symbols are in accordance with BSEN 22553, which supersedes BS 499 and is identical to those in ISO 2553.

WELD DETAILS

Indicating joint position:

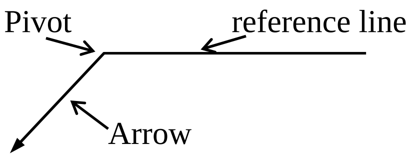
An arrow indicates the position of the joint. The arrow points to one side of the joint. This is called the ARROW SIDE. The side remote from the arrow is called the OTHER SIDE.

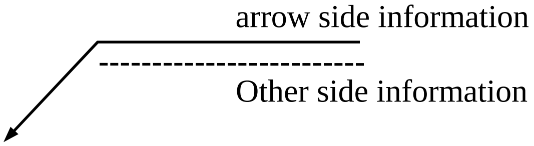




Weld information:

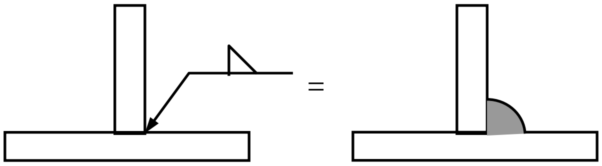
Information about the weld is given on a reference line attached to the arrow at a pivot. The reference line is always horizontal and the arrow can swing about the pivot to point at the weld. Details of the weld on the arrow side of the joint are given on the solid line. Other side information is on the dotted line, which can be shown above or below the solid line.



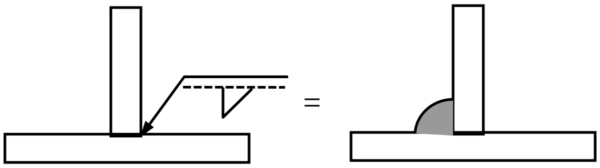


A fillet weld is indicated by a triangle placed on the reference line.

A triangle on the reference line
Specifies a fillet weld on the
Arrow side of the joint.



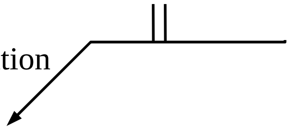
A triangle on the dotted line
Calls for a fillet weld on the
Other side of the joint.-



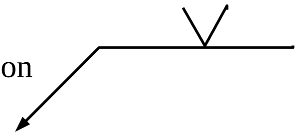
TYPES OF BUTT WELD

The common types of edge preparation associated with a butt weld are indicated as follows:

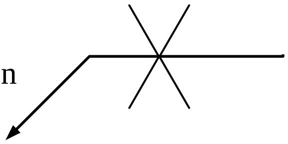
Square edge preparation



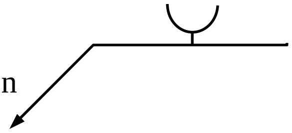
single V preparation



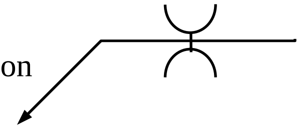
Double V preparation



single U preparation



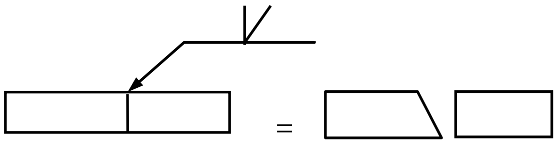
Double U preparation

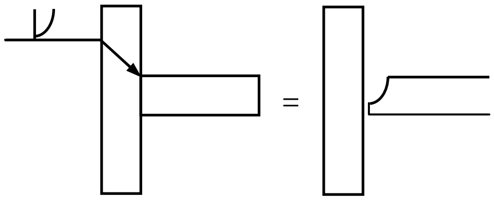


Using symbols it is not necessary to draw the shape of the weld edge preparation. On any Drawing the joint is always shown as a single line.

ASYMMETRICAL PREPARATIONS

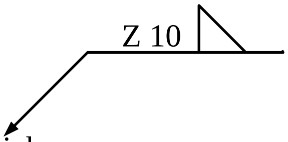
In some joints, only one component is prepared, e.g. single bevel butt or single J butt. In these cases the arrow points at the edge which is to be prepared. The vertical upright of the symbol is always to the left on the reference line.



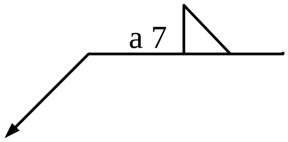


DIMENSIONING FILLET WELDS

The leg length of a fillet weld is located to the left of the weld symbol (triangle). The dimension is in millimetres preceded with the letter Z. Throat thickness is indicated in the same way but is preceded by the letter a. If no letter is shown on a drawing, then assume the dimension is leg length.

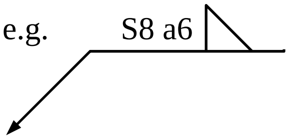


= 10 mm leg length
Fillet weld
thickness



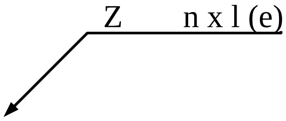
= fillet weld with 7 mm
design throat

For deep penetration welds the dimensions are indicated e.g.
This indicates a weld of 6 mm design throat, with an 8 mm
Actual throat desired. The actual throat thickness is
Proceeded by S.



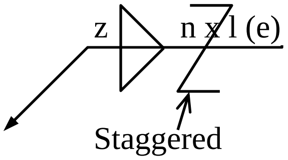
Intermittent fillet welds are dimensioned by giving:

- Number of weld elements (n)
- Length of weld element (l)
- Distance between weld elements (e)

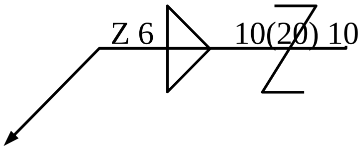


Often the number of weld elements (n) is not specified, usually because it is not known.
The symbol can also be written as l (e) l, the length being repeated. The length is in centimetres.

A symbol thus



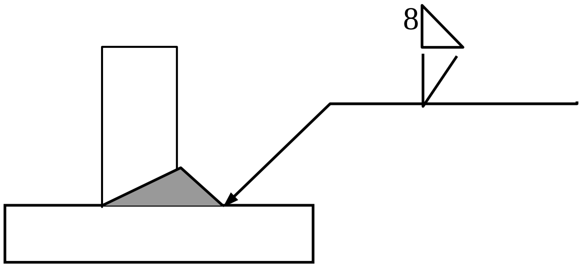
on a double fillet means the weld elements are to be Staggered on either side of the joint.



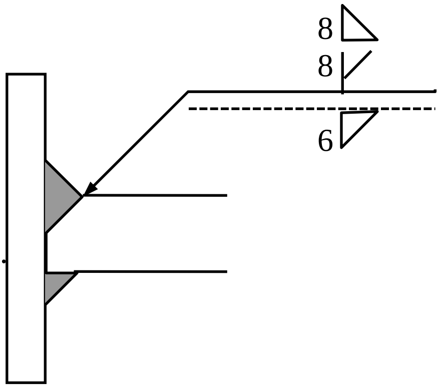
= 6 mm throat fillet welds of 10 cm length with a gap of 20 cm between each element, staggered on either side of the joint, for the whole joint’s length.

COMPOUND WELDS

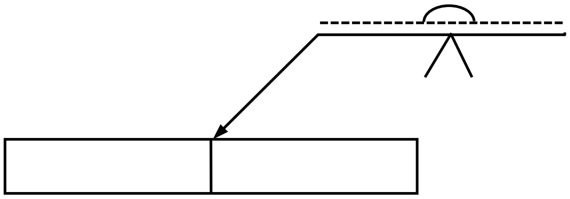
A compound weld is a combination of different welds on the same joint.



= A full penetration single bevel tee Joint with 8 mm fillet reinforcement.



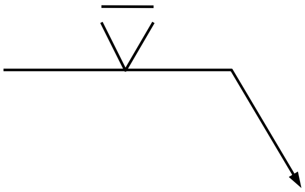
= an 8 mm partial penetration tee joint With an 8 mm fillet reinforcement and A 6 mm fillet on the other side of the joint.



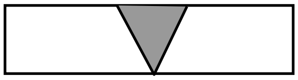
= A single V butt weld with a sealing run along the root side of the weld.

SURFACE PROFILES

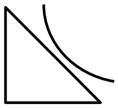
The surface profile can be indicated by an extra symbol placed on top of the weld symbol.



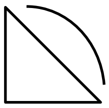
=



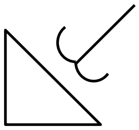
= a single V butt weld with a flat Surface. (Usually flushed after welding by grinding)



= a concave fillet weld.



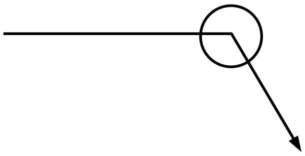
= a convex fillet weld.



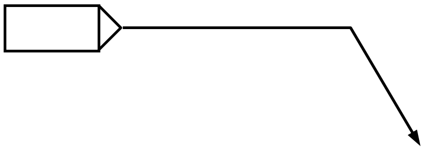
= a fillet weld with blended toes.

SUPPLEMENTARY SYMBOLS

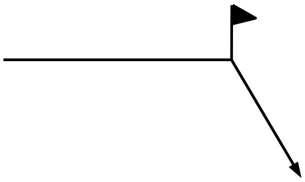
Other symbols in general use:



= weld all round the component.

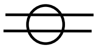


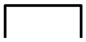
= additional information. (the box on the tail of the reference line can contain information e.g. Weld process, NDT, paint, etc.)



= this weld welded on site. (Field weld)

 = spot weld

 = seam weld

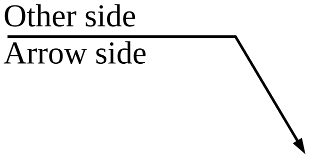
 = plug weld

 = seal weld

 = butt weld between plates with raised edges

BS 499

In the older style, in BS 499 standard, the main difference was that there was no dotted reference line, so below the reference line was the arrow side and above the reference line was the other side.



MATERIALS

ALLOYING ADDITIVES

The term ‘steel’ is used to describe many different metals. They are all alloys based on iron, but the alloying additions, such as carbon, manganese, silicon, chromium, etc., singly or in combination produce a range of metals with widely differing physical and mechanical properties as well as quite different weldibility.

IRON	Fe	the basic constituent.
CARBON	C	gives hardness and strength.
MANGANESE	Mn	gives toughness and strength. Neutralises sulphur.
SILICON	Si	a deoxident - oxide reducer. Usually added through filler wire.
ALUMINIUM	Al	an oxide reducer, grain refiner and adds toughness. (In killed steel the oxygen is removed by aluminium.)
CHROMIUM	Cr	gives corrosion resistance, high temperature strength and creep resistance. (Grain creep occurs over time at high temperatures due to gravity.)
MOLYBDENUM	Mo	gives high temperature creep resistance.
TITANIUM	Ti	Ti and Nb are both grain refiners and stabilising agents. They prevent intergranular corrosion and weld decay. Used in austenitic steels.
NIOBIUM	Nb	
VANADIUM	V	gives hardness and strength.
SULPHUR	S	a contaminant. (Main cause of solidification cracking - ‘hot shortness')
NICKEL	Ni	gives low temperature toughness and strength.
COPPER	Cu	a contaminant - causes liquation cracks. (Though also used for weathering steel and a possible grain refiner.)
PHOSPHORUS	P	a contaminant.

STEEL COMPOSITIONS

Rimming Steel
Composition: 0.09% C 0.9% Mn + residuals
Weldability: The weld pool will require to have added deoxident via a filler rod. Rimming steel is very ductile, cheap and used for pressing and forming. It is low in carbon and high in oxygen - has not been killed (killed = deoxidised).

Low Carbon Steel
Composition: 0.2% C 0.9% Mn + residuals
Weldability: The general weldability is good but the level of residuals (S) may cause weld metal / heat affected zone cracking.

Medium Carbon Steel
Composition: 0.45% C 0.9% Mn + residuals
Weldability: The high carbon content induces hydrogen cracking in the HAZ as the section size increases. Greater than 0.38% C possibly requires heat treatment.

High Carbon Steel
Composition: 0.8% C 0.9% Mn + residuals

Weld-ability: The weld pool is subject to solidification type cracking and the HAZ suffers hydrogen cracking. Not suitable for welding. A tool steel.

Carbon-Manganese Steel

Composition: 0.2% C 1.5% Mn + residuals may also contain Ti, Ni and V.
Weld-ability: These high manganese steels have good toughness, particularly the titanium, niobium, and vanadium grades. The main weld-ability problem is to maintain these.

Quenched and Tempered Steel

Composition: 0.4% C 1.0% Mn 0.8% Cr 0.3% Mo + Ti or Al + residuals
Weld-ability: These steels are difficult to weld, and defect free welds with good mechanical properties are only obtained by using the greatest care.

High Temperature Steel

Composition: 0.25 - 9% Cr 0.25 - 3% Mo + traces
Weld-ability: The weld-ability of the low chromium is difficult. Good grain creep resistance.

Low Temperature Steel

Composition: 3.5 - 9% Ni + traces
Weld-ability: The higher nickel content is subject to solidification cracking.

Micro Alloyed Steel (HSLA)

Composition: 0.25% C 1.5% Mn (0.002% V, 0.005% Nb, 0.003% Ti minimum)
Weld-ability: These steels may suffer hydrogen cracking in the weld metal - the only weld metal to do so. HSLA - High Strength Low Alloy.

STAINLESS STEELS

Martensitic Stainless Steel

Composition: 11% Cr 0.08% C + residuals
Weldability: Poor due to hydrogen cracking.

Ferritic Stainless Steel

Composition: 12 - 27% Cr 0.08% C + residuals
Weld-ability: Poor due to cracking, brittleness and temper embrittlement.

Austinitic Stainless Steel

Composition: 18 - 27% Cr 8 - 22% Ni 0.08% C + residuals
Weld-ability: Problems with solidification cracking and weld decay - but does not suffer hydrogen cracking. N.B. this is *non-magnetic* steel.

CARBON EQUIVALENCY

Carbon equivalency (C.E.) is used to give an overall carbon percentage to estimate the risk of cracking. The higher the carbon content; the harder the steel - the more susceptible it is to cracking. A carbon equivalency of 0.04% and above gives a greater risk of cracking.

$$\text{C.E.} = \%\,\text{C} + \frac{\%\,\text{Mn}}{6} + \frac{\%\,\text{Cr} + \text{Mo} + \text{V}}{5} + \frac{\%\,\text{Ni} + \text{Co etc.}}{15}$$

REVIEW OF STEELS

Types of steel used in welded constructions -

a. Low carbon - These steels are readily weld-able but may be subject to weld metal cracking in the cheaper qualities.
b. Medium carbon - As the carbon content approaches 0.4% steels become prone to parent metal cracking.
c. Low carbon/low alloy - The additional alloying elements acting in a similar way to carbon again produce difficulties in welding.
d. High alloy steels - The austenitic stainless steels are prone to weld metal and reheat cracking due to thermal conductivity characteristics.

The lower grades of constructional steel may exist in a number of forms due to the manufacturing method used and these may exercise some influence on the weld-ability.

Rimming steel has not been deoxidised in the ingot mould and hence during solidification the carbon reacts with the dissolved oxygen and is partly removed as carbon monoxide or dioxide. The centre of the ingot solidifies with large quantities of oxygen entrapped, which may give rise to porosity during welding.

Killed steel is deoxidised and although the resulting non-metallic inclusions may give rise to some other problems porosity is not usually a prime problem.

Air blown acid or basic Bessemer steel will contain nitrogen, which lowers the impact properties due to precipitation of FeN needles. This is becoming less of a problem with the advent of tonnage oxygen and the basic oxygen process in steelmaking.
Deoxidants are varied but aluminium, silicon and manganese are widely used. Aluminium gives the finer grain size, and hence a harder steel. However the fine grain size is lost when temperatures in excess of 350°C are encountered.

Defects in parent materials. -

Many defects that arise in welding are directly due to the quality of the parent plate.
The specified composition plate material is not always achieved in all plates supplied. This is because the composition of the steel in the ladle is changing with time but all the steel cannot be cast instantaneously. Consequently it is quite possible that a welding procedure that works for one plate may not work for another.
A great number of defects are produced during pouring and solidification of the ingot and although some of these may be removed during hot and cold working, others may be produced.

Ingot defects include: surface defects (scabs, laps, etc.), solidification cracks, segregations, inclusions, piping and porosity.
Rolling defects include: cracking and fishtail.
In the plate the most troublesome defects are: laminations, segregations or banding, cracks, porosity and inclusions.

MATERIALS INSPECTION

A great variety of materials may require to be inspected with a view to satisfactory welding. The main topics in material inspection are Size, Type and Condition.

Specification.

It is not, in general, safe for the inspector to identify materials by composition from a mill sheet, since very small variations or additions to the metal may give rise to significant changes in properties and weldability. However limited selectivity is permissible, such as percentage carbon maximum etc. The procedure is for the mill sheet to be submitted for approval and then the inspector records and transfers the reference number.

Supplier.

This can be found on the Goods Inwards documents or the receipt documents, or occasionally on packaging or even marked on the metal.

Quantity.

The quantity being inspected should always be noted as well as the sample size if 100 % inspection is not being employed.

Size.

Sizes must be checked for secondary identification as well as conformance. The inspector will, as appropriate, be given tolerances on size that are permissible. Check length, breadth, thickness and diameter.

Distortion.

A check is often required on the degree of distortion, i.e.
Flatness
Squareness
Straightness
Ovality
Consistent wall thickness

Condition.

Rust, paint and grease on the surface of the metal are all harmful to welding and must usually be removed, at least near to the actual weld. Guidance is normally given to the inspector regarding acceptable levels or the treatment that is required. An inspector should be alert to gradual changes, such as increased corrosion. Carefully maintained specimens showing acceptable conditions are often the best method. Heat treatment condition, annealed, normalised etc., should all be recorded.

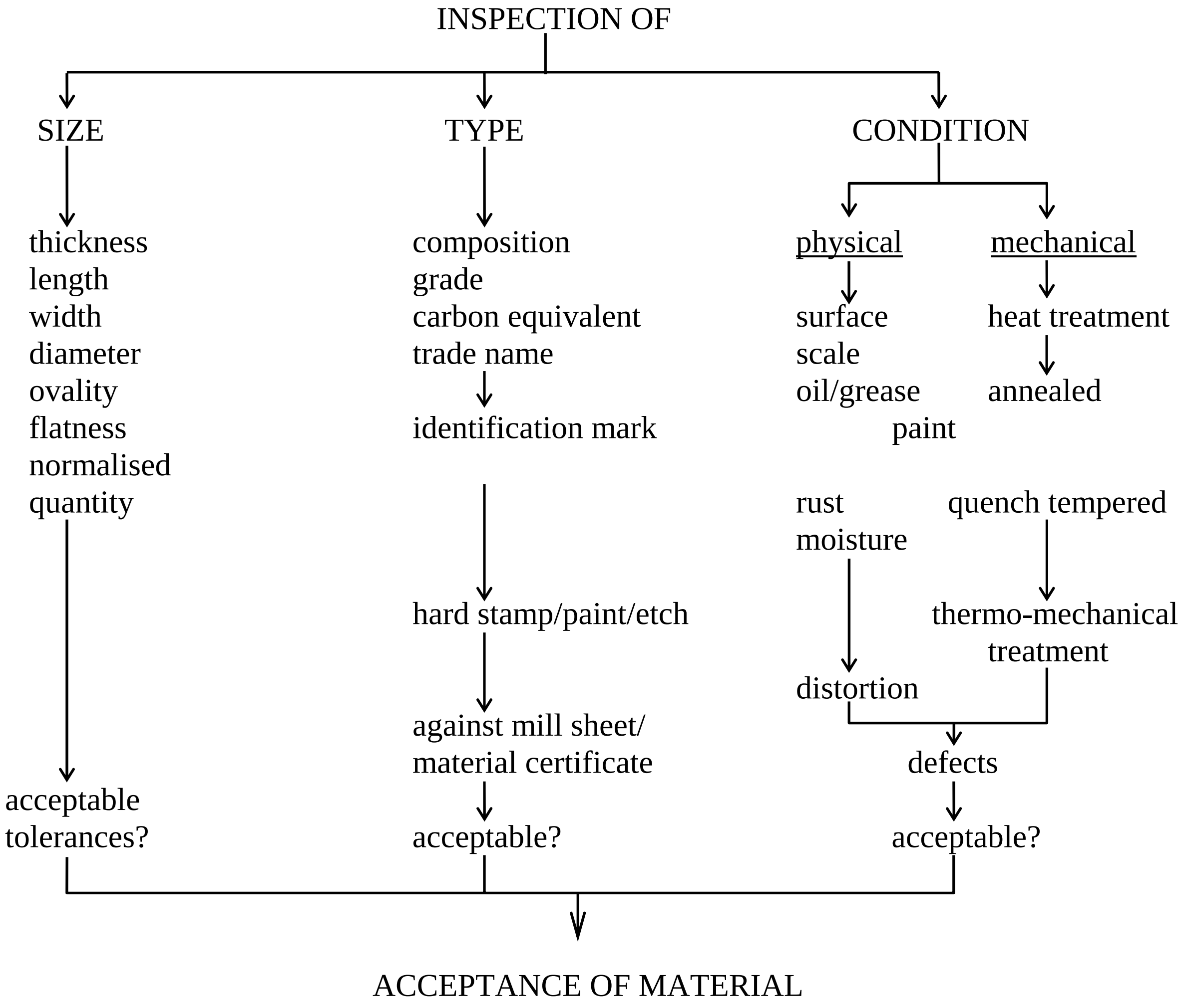
Defects.

In wrought products the most common defects are laps and laminations (Also porosity and segregation bands.) These will normally be subsurface so, unless NDE is employed, only the edges of the plate, and particularly cut edges, can be inspected. The lap/lamination will appear as a narrow black line parallel to the surface.

Storage.

After inspection and approval for use it is essential that the metal is stored in such a way as to maintain its good condition. Protect from corrosion and mechanical damage.

MATERIALS INSPECTION CHECK LIST



QUESTIONS TO BE ASKED

1. Do the markings on the material match those on the procedure sheet or drawing?
2. Are the dimensions correct?
3. Is the surface condition satisfactory for welding?

THE FOUR ESSENTIAL FACTORS FOR ESTABLISHING A WELD

Welding is usually regarded as a joining process in which the work pieces are in atomic contact often with a filler metal with broadly similar properties. Hence soldering and brazing are excluded but both solid state and fusion welding are included.

Solid state processes include:
- Forge welding.
- Friction welding.

Fusion welding processes include:
- Oxy-acetylene.
- Manual metal arc (MMA).
- Metal inert/active gas (MIG/MAG).
- Submerged arc welding (SAW).
- Electro-slag welding (ESW).

<u>FUSION WELDING FACTORS</u>

1.	Fusion.	The metal must be melted which requires a high intensity heat source.
2.	Atmospheric protection.	Contamination from the atmosphere must be avoided.
3.	Surface protection.	The process must remove any oxide and other contamination from the joint faces.
4.	Adequate properties.	The welded joint must possess adequate mechanical, metallurgical and physical properties.

Examples of the four factors:

TIG	fusion source	electric arc between wire and workplace.
	atmospheric protection	argon gas.
	surface protection	deoxidants in wire, mechanical cleaning.
	properties	from filler wire (possibly pre/post weld heat treatment).
MMA	fusion source	electric arc between electrode and workplace.
	atmospheric protection	gaseous shield from flux.
	surface protection	mechanical cleaning, slag, fluxing (cleaning) action.
	properties	alloying elements in flux, baking electrodes, pre and post weld heat treatment.

WELDABILITY

INTRODUCTION

As a result of the heat input to which the steel is exposed in any form of welding the material undergoes certain changes, some of which are permanent. Amongst these changes are structural transformations during heating and cooling and changes in shape or size due to the thermal stresses. Steel, which can be welded without any dangerous consequences resulting from these changes, is said to possess *good* ***weld-ability***. If, on the other hand, the changes due to a normal welding process are in serious danger of causing failure in a welded component, or if actual defects such as cracking occur during welding, the steel is said to possess *limited* ***weld-ability*** and can in most cases be welded, without risk, provided certain precautions are taken or certain pre- or post- welding treatments are carried out. The term ‘un-weld-able steels’ is unrealistic. Any steel can be welded provided correct metallurgical conditions are chosen. Sometimes, however, these conditions may be impossible to realise in practical production work.

WELDABILITY OF STEEL

Weld-ability is a function of many inter-related factors but these may be summarised as:

1. Process and technique.
2. Composition of parent plate.
3. Joint design and size.

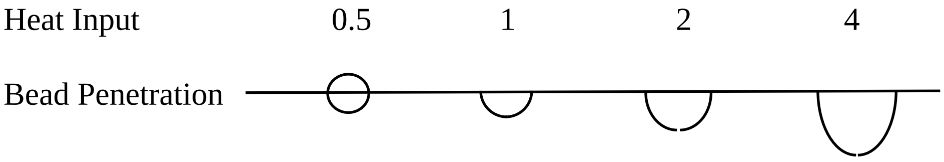
INFLUENCE OF PROCESS

Each process will give a characteristic intensity of power. Processes that offer the higher power intensity offer advantages in fusion welding because the essential melting can be obtained without excessive heat inputs with the consequent thermal expansion of the parent metal.
Successful welding often depends on feeding into the weld pool a filler wire which carries a deoxidant (or ferrite forming elements) hence processes which do not use filler wire are limited in application.

HEAT INPUT

Heat input is a combination of voltage, amperage and travel speed.

$$\text{Heat Input} = \frac{\text{voltage x amperage}}{\text{travel speed}}$$



Hardness	475	450	300	275

(with hardness, the higher the number, the harder the material)

Toughness - resistance to bending and impact
Hardness - resistance to penetration

As heat input increases:	grain size increases	toughness decreases
	brittleness increases	hardness decreases
		incidence of cracking decreases

PREHEATING

There are four general factors that must be assessed to determine the level of preheat.

1. Material type.
2. Combined thickness.
3. Heat input potential (welding process).
4. Joint type.

INFLUENCE OF COMPOSITION

The composition of the steel and its effect on weld-ability may be divided into two parts:

1.Segregation effects, particularly that of sulphur.

When a steel solidifies, there is a tendency for the iron to solidify fast and for the alloying elements to be accumulated in the centre of the ingot. This configuration is retained even after prolonged and severe rolling and results in high concentrations of sulphur in the central layers of the plate. These layers have little strength and are likely to crack if stressed.

2. The tendency of the steel to harden.

The hardening characteristics of steel are mentioned in the heat treatment section. As the carbon or alloy content of the steel increases, the likelihood of low ductility and hardened microstructures forming also increases and should stresses exist, cracking will result.

WELD AND HAZ CRACKING

These are the main causes of cracking:

a. High levels of carbon and other alloy elements result in brittle zones around the weld.
b. High cooling rates after welding increase the hardness, which increases the susceptibility to cold cracking.
c. Joint restraint prevents contraction after welding, which can lead to internal cracking.
d. Hydrogen in the weld bead can lead to hydrogen induced cold cracking.
e. Contaminants like sulphur and phosphorus cause segregation or solidification cracking.
f. Lamellar tearing caused by inclusions layering during rolling resulting in deterioration of the through-thickness properties.

Cracking usually occurs in the unmelted areas adjacent to a weld bead (in the heat affected zone, HAZ). This zone is made up of an area that has been heated to above about 800°C (to become austenite), and an area heated above 723°C (and partially transformed). The fully austenitic region just adjacent to the fusion zone is often the most brittle area of the weld due to the grain growth that has occurred while the metal was at this temperature. The grain size gradually decreases moving away from the fusion zone to the partially transformed region. Grain refinement occurs here, which is considered beneficial, the grain size being smaller.

The composition of the steel, particularly the carbon level, determines the hardness and brittleness of both the weld and the HAZ. On cooling, austenite transforms to ferrite. Carbon is soluble in austenite, but less so in ferrite. Iron carbides are precipitated when this transformation takes place. These can be arranged in lamellar form (as pearlite), which gives the structure reasonable strength and ductility.

The HAZ can be the region where the highest cooling rates occur, particularly in thicker section plate. High cooling rates tend to lock the carbides in a solid solution, forming martensite. This leads to high internal stress and hard brittle structures.

TYPICAL WELDABILITY DEFECTS

1. SOLIDIFICATION CRACKING.

Also known as hot cracking or centreline cracking. Always occurs in the weld metal.
Causes - In carbon manganese steels; sulphur in the parent plate, shape of the weld, stress - always needed.

Sulphur.
During solidification the centre of the weld is the last to cool. Sulphur from the parent plate forms iron sulphide with iron from the weld pool. The iron sulphide forms a thin liquid film on the grain boundaries, which has a lower melting point than iron, so as the weld cools it is pushed towards the centre of the weld. The iron sulphide has very little tensile strength, so as it cools, the weld is under stress and cracking will result. Phosphorous contamination in the material can also cause solidification cracking.
Avoidance - Reduce sulphur (check mill sheets for levels < 0.03 %).
Cleaning (no oil, grease etc.).
Add manganese to the parent plate via the filler wire (forms manganese sulphide that melts cools at approximately the same temperature as steel. Manganese sulphide is more discreet therefore less cracking.).
Reduce dilution by reducing the weld size.

Shape.
Deep and narrow weld preparations are susceptible. As a weld cools, grains grow from the extremities towards the centre of the weld. In a narrow prep, as the grains grow towards the centre, they interfere with each other's growth. This grain impingement causes voids between the grains and cracking will result.
Avoidance - Wider weld preparation (increase the included angle and / or gap size).

2. HYDROGEN CRACKING.

Also known as under bead cracking, hard zone cracking and hydrogen induced cold cracking (HICC). This phenomenon can occur during the welding of hardenable steels, and is normally a HAZ phenomenon. Hydrogen is more soluble in austenite than ferrite - it can easily be picked up by the weld metal. When ferrite is formed the hydrogen solubility decreases, and hydrogen diffuses to the HAZ where it can contribute to crack propagation.
There are four factors involved in hydrogen cracking. Avoid one factor and hydrogen cracking will not occur.

Factors.

1.	hydrogen	> 15 ml hydrogen per 100 mg weld metal
2.	temperature	< 350° C
3.	hardness	> 400 VPN (Vickers pyramid number)
4.	stress	> 50 % yield (cannot be measured so assume it is > 50 % yield)

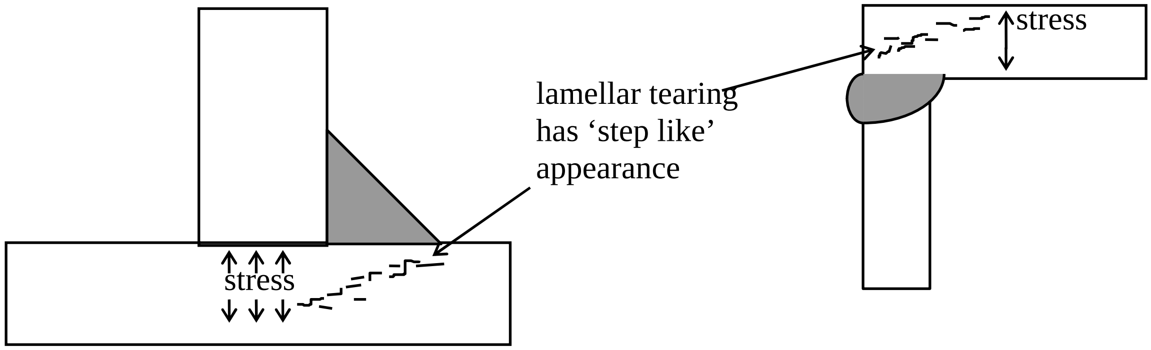
Avoidance.

1. Hydrogen
   - a) parent material dried (free from moisture).
   - b) low hydrogen rods (baked to less than 5 ml per 100 mg).
   - c) use lower potential hydrogen process. (hydrogen potential - electron < TIG < MIG/MAG < SAW, MMA (low H) < MMA (rutile))
   - d) heat treatment (pre and post weld).
2. Temperature
   - post weld heat treatment. (keep at a higher temperature as long as possible to help hydrogen diffusion. NDT as late as possible - 72 hours.).
3. Hardness
   - a) preheating (to reduce the cooling rate)
   - b) keep interpass temperature to a minimum
   - c) higher heat input (gives a larger grain size)
   - d) post weld heat treatment -tempers hard HAZ, removes H_2, reduces stress
4. Stress
   - a) joint design
   - b) fit up
   - c) distortion control
   - d) stress relieve treatment (pre and post weld)

On high micro alloy steels it may occur in the weld metal, otherwise only in the HAZ.

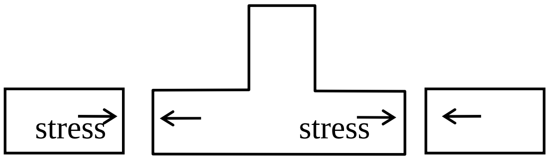
3. LAMELLAR TEARING.

A step like crack that occurs in thick section tee joints and closed corner joints.

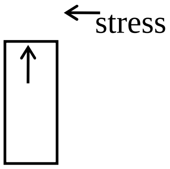


Causes - Poor through thickness ductility in parent plate where high shrinkage strains (through thickness stress) act through the plate thickness in combination with parent metal inclusions. The inclusions can be lamellar inclusions, small micro inclusions or tramp elements. Only occurs on the leg with stresses on the non-rolling direction / through thickness.

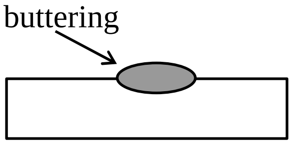
Avoidance - Joint design (use pre-formed tees, use open corners).
Use buttering layer (possibly more ductile and will take up some of the shrinkage).
Use Z grade steel (has been tested in the short transverse direction using a STRA test - Short Transverse Reduction in Area).



pre formed tee



open corner



buttering

4. WELD DECAY IN AUSTENITIC STAINLESS STEELS

Occurs in the HAZ due to the precipitation of chromium carbides. In the 550° C - 850° C range, the chromium leaches out of the grain and reacts with the carbon to form chromium carbides, due to the chromium having a greater affinity for carbon. This results in a chromium deficiency in the grains. The chromium is in the grains for corrosion resistance, so when the chromium is lost, decay (‘rusting’) occurs very quickly. The longer a zone is in the temperature range of 550° C to 850° C the greater the area is susceptible to decay. This temperature range is usually just off the weld.

Avoidance - Reduce carbon - Use low carbon rods for example 316 L. But low carbon reduces strength, so a stabilised stainless steel could be used with high carbon content but with titanium and niobium added. (Carbon has a greater affinity for titanium and niobium therefore titanium and niobium carbides are produced instead of chromium carbides).
Lower heat input - less time in the 550° C - 850° C temperature range.
Quench cool - less time in the 550° C - 850° C temperature range.
Keep interpass temperature low.

The keyword is precipitation (of the chromium). The material is then said to be sensitised - put it in seawater, it rusts.

WELDING OF CARBON STEEL

These steels are also known as carbon-manganese and plain carbon steels. They are usually welded with mild steel consumables without problems, but the weldability decreases with increasing carbon levels or C.E. (carbon equivalent) values.

The very low carbon steels (C < 0.15%) can produce porosity when welded at high speed. This problem can be overcome by increasing the heat input.

Steels with carbon contents between 0.15% and 0.25% are preferred for welding, as they rarely present weldability problems if the impurity levels are kept low. The steels with carbon levels higher than 0.25% can be susceptible to cracking if other hardening elements like Mn and Si are present in fairly high percentages. These steels are best welded with low hydrogen processes or electrodes, and thick sections may require some pre-heating to reduce the cooling rate.

The high carbon steels are used for their wear resistance and hardness (for example tool steels). They are generally very brittle and require pre-heating, interpass heating and post weld stress relief to prevent cracking.

Most medium carbon steels require one or more of the above treatments depending on carbon level and joint thickness. They are always welded with low hydrogen processes or consumables and it is usual to perform a weldability test before production welding.

WELDING OF LOW ALLOY STEELS

The most common low alloy steels are the nickel steels, the carbon-molybdenum and the chromium-molybdenum alloys.

Nickel from 2% to 5% in a 0.15% to 0.25% carbon steel provides a combination of high strength and high toughness at low temperatures. If the carbon level is below 0.18% welding can be done without pre-heat. Above this level, similar precautions to those recommended for medium carbon steels should be adopted.

The carbon-molybdenum and chromium-molybdenum steels are used for high temperature applications as they have high creep resistance and high strength. Below 0.18% carbon no pre-heat is required, but thicker sections with higher carbon levels are hardenable in air and therefore crack sensitive. For very high carbon levels (0.55%) where welding is not recommended, an austenitic stainless steel consumable can sometimes be used. The weld will have more ductility and less strength than the parent plate and will relieve some of the internal stress. The HAZ will still be brittle, however, making pre-heat essential.

WELDING OF HIGH YIELD QUENCH AND TEMPERED STEELS

These steels have martensitic structures that are formed by heat treatment during manufacture. One of the most common of these steels is HY80, which is used on submarine hulls.

The steels rely on relatively high cooling rates for the strong martensitic structures to form. Strength can be lost if the cooling rate is too slow. Too high a cooling rate, however, can cause weld cracking. Both the minimum pre-heat temperature and the maximum inter-pass temperature have to be carefully controlled to achieve the correct structure without cracking. Matching consumables are usually used. Weaving should be limited to a maximum of 15mm to keep the heat input down.

WELDING OF HIGH STRENGTH LOW ALLOY STEELS

Most of these steels do not rely on heat treatment for their strength. They have ferritic structures with low carbon levels (0.2% and less) and small amounts of alloying elements in solution (Mn, Cr, Ti, V, Nb, N).

There are many different types with varying degrees of strength, toughness and corrosion resistance. They usually have good weldability, but the high strength does make them more susceptible to cracking than low carbon steel. High heat inputs are usually recommended and pre-heating is sometimes required.

SUMMARY

BS 5135 states that weld-ability is the ability of a material to be joined by most of the weld processes and still maintain most of the physical/mechanical properties for which it was originally designed.

Good weldability - low risk of HICC, but solidification cracking risk due to poor grain structure.
Limited weldability - may risk hardening effects through welding / cutting and HICC.
Lamellar tearing - poor through thickness ductility and plate defects.

Avoidance of the above risks should lead to an ‘acceptable’ weld.

RESIDUAL STRESS AND DISTORTION

RESIDUAL STRESS

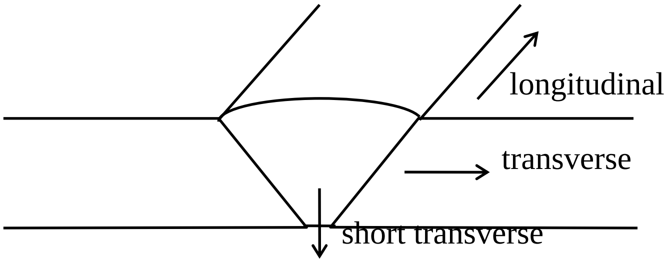
Metals contract during solidification and subsequent cooling, but if this contraction is prevented or inhibited, residual stresses will develop. During normal cooling smaller grains develop first towards the edges of the weld and larger grains develop in the middle of the weld as it cools. Most material products contain residual stresses, often up to yield point. Pipe products, for example, are usually very highly stressed.
The tendency to develop residual stresses increases when the heating and cooling are localised. So welding with its very localised heating and the presence of liquid and solid metal in contact can be expected to induce very high levels of residual stresses.

Residual stresses are a combination of unequal expansion / contraction coupled with restraint.

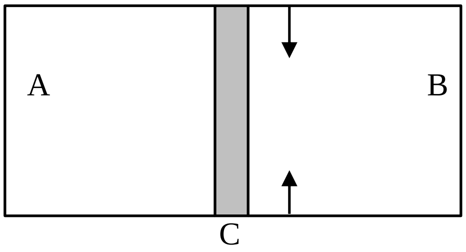
Residual stresses can be difficult to measure with any real accuracy, but a rough guide is that when the weld metal exceeds two cubic inches (fourteen cubic centimetres) then the total residual stress is about yield point in magnitude.

Normal welds develop the following residual stresses:

a) along the weld - longitudinal residual stress.
b) across the weld - transverse residual stress.
c) through the weld - Short transverse residual stress.

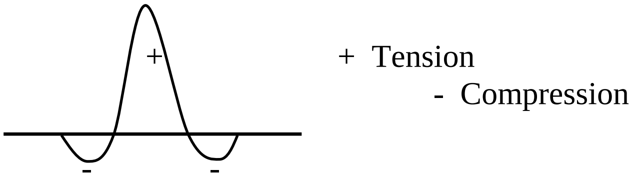


Longitudinal Residual Stresses.

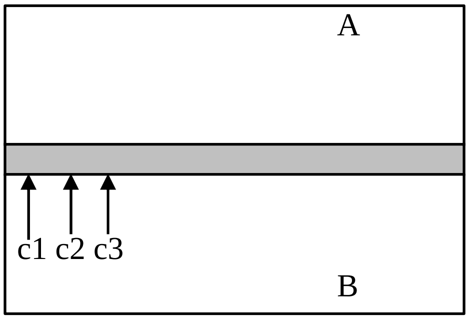


Consider the two plates A and B joined by the weld metal C. The weld metal and the HAZ want to contract, but this is resisted by the plates. So the weld metal and the HAZ are pulled out (placed in tension) and the plates are pulled in (placed in compression).

This can be shown diagrammatically:



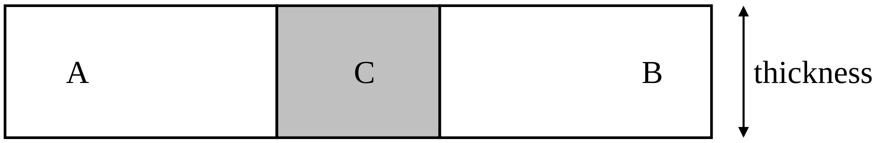
Transverse Residual Stresses.



Again consider two plates A and B with weld metal C. In order to see how the stresses develop we must look at the deposition of small lengths of weld C1, C2, C3 etc.

Assume that the plates A and B are not restrained. Length C1 will contract and draw the plates together so the level of residual stresses across the joint will be very low. Length C2 will attempt to contract but C1 will prevent this, so (roughly) C1 is placed in compression and C2 in tension. Length C3 also attempts to contract but is now prevented by C2, which is placed in compression, and C1 is pulled into tension. So we find there is a reversal of transverse residual stresses along the joint. This pattern is similar for a multipass weld.

Short Transverse Residual Stresses.



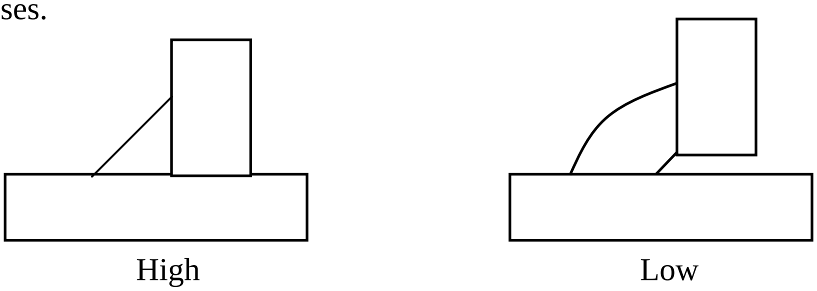
Again consider plates A and B joined by weld metal C. The effect is like that of the longitudinal residual stresses if the weld is a single pass. For multipass welds the condition is more like the transverse residual stresses and we find tensile stresses at the surface and compressive stresses at the centre.

Total Residual Stresses.

In practice the three directions in which the residual stresses develop combine to give a resultant or total residual stress.

Effect of restraint.

For any given welded joint the level of residual stresses tends to increase as the restraint on the joint increases.



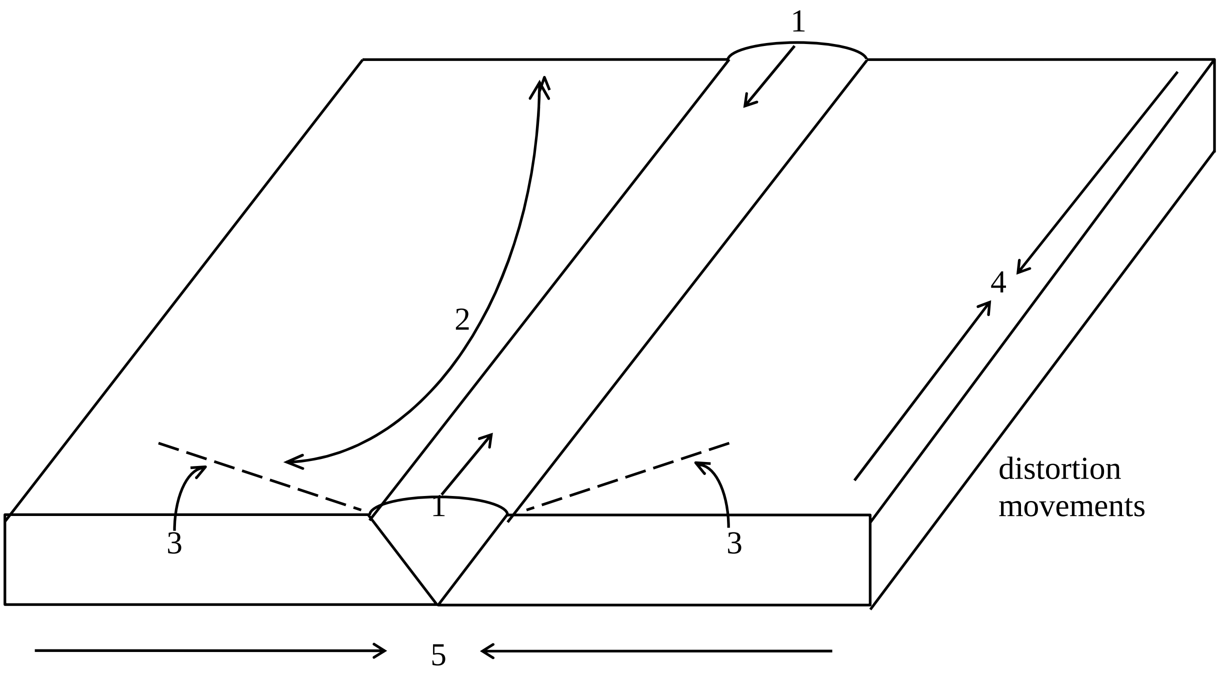
Reducing restraint will reduce residual stress and reduce the chance of cracking.

DISTORTION

The action of residual stresses in welded joints is to cause distortion.

Consider a simple weld with a single V preparation.
The following movements can be detected:

1. Contraction in the weld metal and HAZ along the length of the weld.
2. Bowing, due to the greater volume of metal at the top of the weld.
3. Peaking due to the V angle.
4. Ripple (in sheet) away from the weld.
5. Contraction in the weld metal and HAZ transverse to the weld.



Control of distortion is achieved in one or more of three main methods:

1.Presetting - so that the metal distorts into the required position.
2.Clamping - to prevent distortion, but this increases the level of residual stresses.
3.Welding sequence - i.e. balanced, for example backskip welding.

Other methods of distortion control include:

Preheating
Change of prep to a more open prep (e.g. a U prep).
Lower heat input.
Pulse welding.

HEAT TREATMENT

Many metals must be given heat treatment before and after welding. The inspector's function is to ensure that the treatment is given, and given correctly, to the details supplied.

Below are the types of heat treatment available. The temperatures mentioned are for steel.

Process	Temperature	Cooling	Result
Annealing	920° C	hold, furnace cool	annealing is a recrystalisation
			improves ductility (softens)
		very slow cool	decreases toughness
			makes bending, etc. easier
			lowers yield stress
Normalising	920° C	hold, air cool	increases toughness
			improves mechanical properties
		slow cool	relieves internal stress
Quench, harden	920° C	hold, quench cool	hardens carbon steels
			prevents carbide precipitation in
			austenitic stainless steels
		fast	prevents temper brittleness
when		(in oil or water)	cooling after tempering
			prepares metal for tempering
Temper	550° C - 700° C	hold, air cool	increases toughness of quenched
		slow	steels
Stress Relief	550° C - 700° C	hold, air cool	relieves residual stresses by
			plastic deformation
			reduces yield point
			reduces hydrogen levels

		slow	improves stability during machining prevents stress corrosion cracking
Preheat for welding	50° C - 250° C	hold	
Hydrogen soak	≈ 150° C	hold	

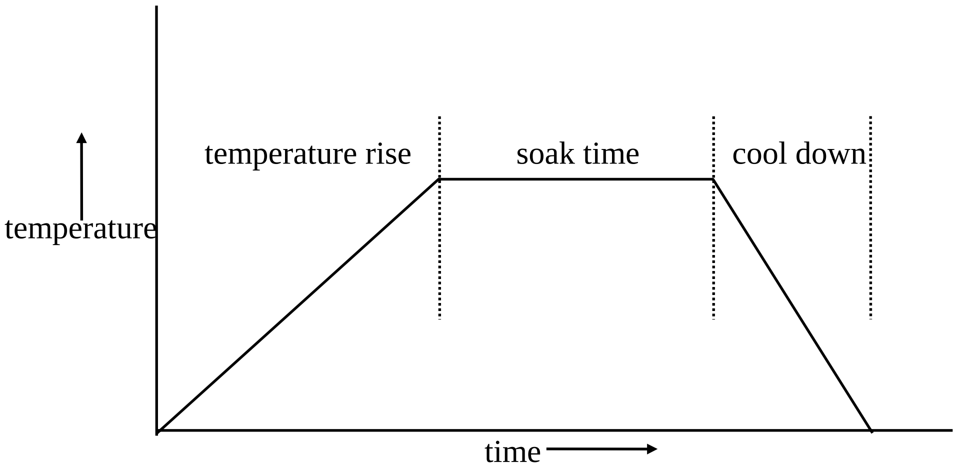
Above 920° C the grain structure and size of grain structure are affected. Below 900° C the grain structure is not affected. The soak time is related to thickness, usually one hour per 25 millimetres thickness. Differing cooling rates give different properties to the metal, so the cool down rate is also critical. (Possibly monitoring at a stand off from the weld being treated.) For preheating and hydrogen soak oxy-acetylene is not to be used (too localised a heat source), propane is to be used.

MONITORING THE HEAT TREATMENT

The method and location of the heat treatment are important, for example in a workshop furnace or on site using electroblanket (cooperheat type) equipment. The temperature is measured with thermocouples and recorded on a chart. The main points are:

- controlled heat rise
- soak time
- temperature
- cool down rate to unrestricted

The last test is a hardness test after cooling.



Typical heat treatment chart recording.

The inspector should ensure that:

a) Equipment is as specified and calibrated.
b) Operators are qualified.
c) Procedure as specified is used.
i.e. method of application, rate of heating and cooling, maximum temperature, soak (holding) time, temperature measurement.
d) All documentation and records are in order.

CALIBRATION OF WELDING EQUIPMENT

Instrumentation fitted to arc welding equipment often becomes inaccurate through neglect, damage, wear etc. The presence of errors in the readings may remain unknown and their extent unchecked. As a result, the values of the welding parameters indicated may well lie outside the working tolerances. Consequently problems may be experienced in achieving the desired weld quality. A significant level of defects may be predicted with consequential costs of reworking, repair or even scrapping.

In high quality welding, regular checking of the parameters is there essential and should form a mandatory part of inspection / quality control.

There are many different types of calibration equipment available, including ammeters, voltmeters or equipment specifically designed to measure all the welding parameters.

Whatever the type of calibration piece used, they must also be calibrated for accurate measurement - usually to a national standard. The British standard for calibrated measuring devices is NAMAS - the National Measurement Scheme. The British standard for arc welding equipment is BS 7570. Calibration is carried out on any equipment with a gauge; validation is carried out on equipment without gauges.

CHECKLIST FOR CALIBRATING ARC WELDING EQUIPMENT

Welding Inspection necessarily involves checking that the correct welding/cutting process is being used, that the equipment is in workable condition and that the welding parameters of amperes and volts are being adhered to.

Welding current:

The main parameter controlling heat input and penetration. Check with ammeters for inaccuracies, usually with tong testers generally anywhere, but preferably as close to the torch as possible. Tolerance +/- 3 %.

Arc voltage:

Which is related to arc length and responsible for the weld bead profile. Check with voltmeter (multimeter) across the electrical circuit for inaccuracies as close to the arc as possible, but not on the return lead. Tolerance +/- 5 %.

Wire feed speed:

The most important parameter in MIG/MAG and SAW. It determines the welding current being drawn to a) melt the wire and b) fuse the workpiece. Check with a stopwatch for 15 - 30 seconds or preferably with a tachogenerator for inconsistency and inaccuracies. The wire feed speed is considered more accurate than amperage because it can be physically measured.

Travel speed:

Determines heat input and penetration.
mechanised - pre-set travel speed and check meter against distance travelled in one minute.
manual - check run out length.

In recent years more attention has been given to quality assurance in arc welding operations and in many cases it is of paramount importance to ensure that the correct welding parameters are being used in order to meet these requirements. Accurate calibration of equipment therefore is necessary and ‘certificates of calibration’ are required for all equipment. i.e. welding equipment, measuring equipment, storage ovens etc.

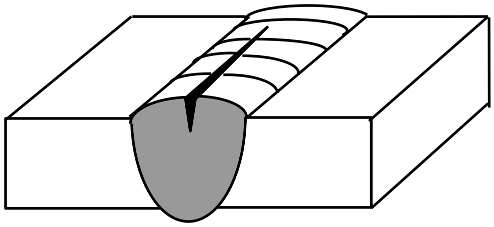
DEFECTS DETECTED BY SURFACE INSPECTION

Defects, which can be detected by visual inspection, can be grouped under five headings.

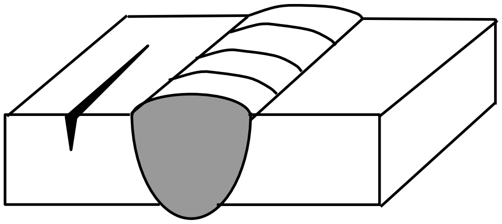
1. Cracks.
2. Surface irregularities.
3. Contour defects.
4. Root defects.
5. Miscellaneous.

1. SURFACE CRACKS

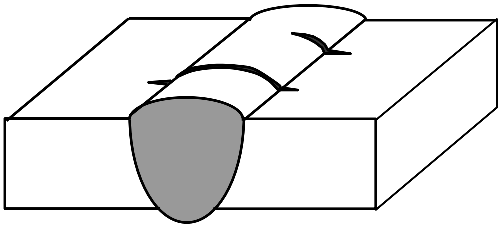
A crack is a linear discontinuity produced by fracture. Cracks may be longitudinal, transverse, edge, crater, centreline, fusion zone, underbead, weld metal or parent metal.



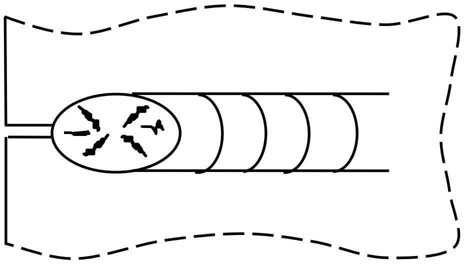
longitudinal, in the weld metal (centreline)



longitudinal, in the parent plate



transverse



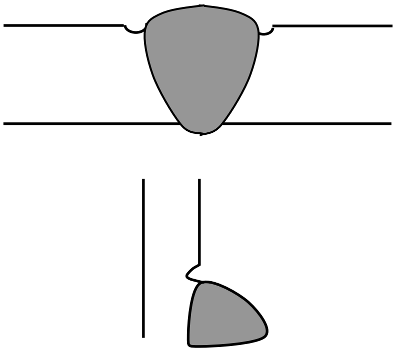
crater (star cracking)

2. SURFACE IRREGULARITIES

Undercut.

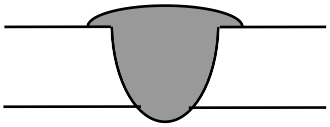
An irregular groove at a toe of a run in the parent metal or in previously deposited weld metal. If created sub-surface it becomes a very effective slag trap in the body of the weld. Undercut is essentially a notch that in turn becomes a focal point for stress loading, thereby reducing the fatigue life of the joint.

Causes - current too high, voltage too high, travel



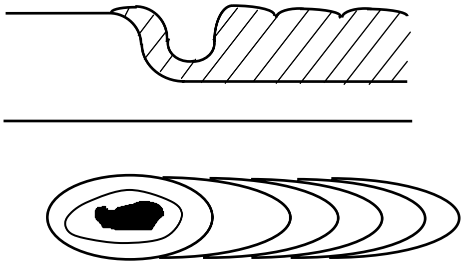
speed too high, electrode too small, electrode angle.

Overlap.



An imperfection at the toe or root of a weld caused by caused by weld metal flowing on to the surface of the parent plate without fusing to it.
Causes - slow travel speed, large electrode, tilt angle, poor pre-cleaning.

Crater pipe.



A depression due to shrinkage at the end of a run where the source of heat was removed.
Causes - breaking the arc too quickly, too rapid cooling.

Spatter.

Stray globules of weld material, on parent plate outside the weld.
Causes - damp electrodes, too high voltage, too high current, flux missing.

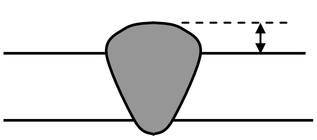
Stray flash (stray arcing)

The damage on the parent material resulting from the accidental striking of an arc away from the weld. A small volume of base material is melted when the arc is struck. This molten pool is quenched due to the rapid diffusion of heat through the plate. This may lead to the formation of a crater that lends itself to cracking, or a change in grain structure by creating a martensitic or brittle grain structure in the area of the arc strike. These discontinuities may lead to extensive cracking in service.
Causes - operator error.

3. CONTOUR DEFECTS

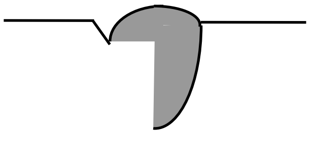
The profile of a finished weld may considerably affect performance of the joint under load bearing conditions. Specifications normally include details of acceptable weld profiles to be used as a guide.
(The ideal profile is to remove the cap and leave the weld flush with the adjacent surfaces. This would increase the fatigue life of the joint by a factor of 3.)

Excess weld metal.



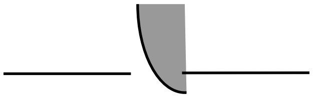
Also excess convexity, excess reinforcement.
Additional weld metal above the surface plane of the parent material or greater than the desired throat on fillet welds.

Lack of fusion.



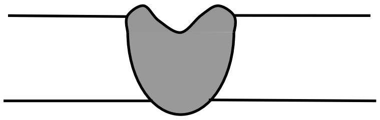
A continuous or intermittent groove along the side of

the weld with the original weld prep face still intact.
Causes - not enough runs, operator error.



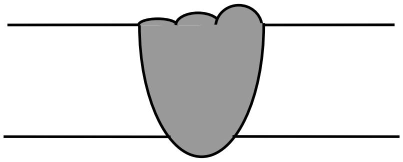
Incompletely filled groove.

A continuous or intermittent channel in the surface of the weld, running along its length, due to insufficient weld material. The channel may be along the centre or along one or both edges of the weld.
Causes - not enough runs - procedure error, electrode too small. Also called insufficient throat.



Bulbous contour.

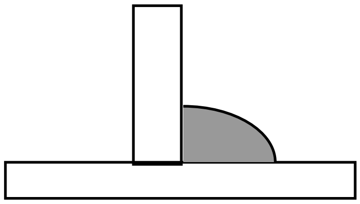
Not a BS 499 term. (possibly under contour / toe blend) Unevenly sized capping runs.
Causes - electrode type, arc voltage conditions, welder technique.



Unequal legs.

Not a BS 499 term. Variation of leg length on a fillet weld.
Causes - tilt angle, run sequence.

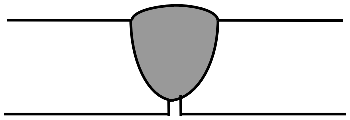
N.B. Unequal legs may be specified as part of the design - in which case they are not defects.



4. ROOT DEFECTS

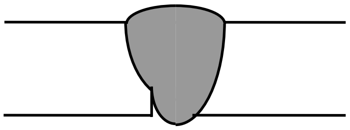
Incomplete root penetration.

Failure of weld metal to extend into the root of the weld.
Causes - poor weld prep, root gap too small, root face too big, small included angle, heat input too low.



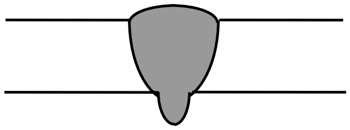
Lack of root fusion.

Lack of union at the root of a joint.
Causes - poor weld prep, uneven bevel, root face too large, linear misalignment, cleaning.



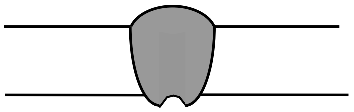
Excess penetration bead.

Excess weld metal protruding through the root of a fusion weld made from one side only.
Causes - high heat input, poor weld prep - large included angle.



Root concavity. (suck-back, underwashing)

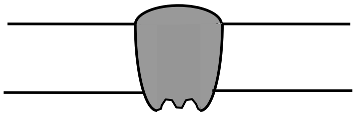
A shallow groove which may occur in the root of a butt weld.
Causes - purge pressure, wide root gap, and residual stresses



in root.

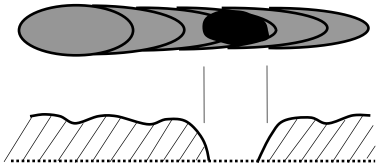
Shrinkage groove.

A shallow groove along each side of a penetration bead. Causes - contraction of the metal along each side of the bead while in the plastic condition.



Burnthrough. (melt through, blowthrough)

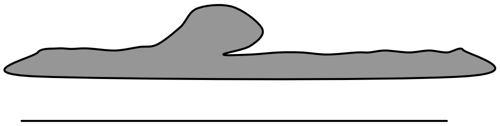
A localised collapse of the molten pool resulting in a hole in the weld run.
Causes - excess penetration, excess heat input (usually at the end of a run), localised weld prep variations.



5. MISCELLANEOUS

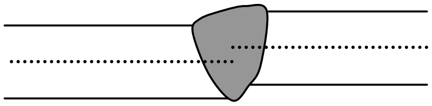
Poor restart.

Non-standard term. A local surface irregularity at a weld restart.



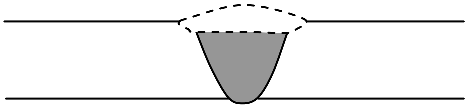
Misalignment.

Non-standard term. Misalignment between two welded pieces such that their surface planes are not parallel or at the intended angles.



Excessive dressing.

A reduction in metal thickness caused by the removal of the surface of a weld and adjacent areas to below the surface of the parent metal.



Grinding mark.

Grooves on the surface of the parent metal or weld metal made by a grinding wheel or surfacing tool.

Tool mark.

An indentation in the surface of the parent metal or weld metal resulting from the application of a tool, e.g. a chipping tool, in preparation or dressing.

Hammer mark.

An indentation in the surface of the parent metal or weld metal due to a hammer blow.

Torn surface.

A surface irregularity due to the breaking off of temporary attachments.

Surface pitting.

An imperfection in the surface of the parent metal usually in the form of small depressions.

INTERNAL DEFECTS

DEFINITIONS.

Lack of fusion.	Lack of union in a weld. a. between weld metal and parent metal. b. between parent metal and parent metal. c. between weld metal and weld metal.
Lack of sidewall fusion.	Lack of union between weld metal and parent metal at a side of a weld.
Lack of inter-run fusion.	Lack of union between adjacent runs of weld metal in a multi-run joint.
Inclusion.	Slag or other foreign matter entrapped during welding. The defect is more irregular in shape than a gas pore.
Oxide inclusion.	Metallic oxide entrapped during welding.
Tungsten inclusion.	An inclusion of tungsten from the electrode during TIG welding.
Copper inclusion.	An inclusion of copper due to the accidental melting of the contact tube or nozzle in self adjusting or controlled arc welding or due to pick up by contact between the copper nozzle and the molten panel during TIG welding.
Puckering.	The formation of an oxide covered weld run or bead with irregular surfaces and with deeply entrained oxide films, which can occur when materials forming refractory oxides (e.g. aluminium and its alloys) are being welded.
Porosity.	A group of gas pores.
Elongated cavities.	A string of gas pores situated parallel to the weld axis. (Linear porosity.)
Blowhole.	A cavity generally over 1.5mm in diameter formed by entrapped gas during the solidification of molten metal.
Wormhole.	An elongated or tubular cavity formed by entrapped gas during the solidification of molten metal.

GENERAL CAUSES

Porosity.	Is the result of gas being entrapped within the solidifying weld metal. Porosity will be present in a weld if the welding technique, materials used or condition of the weld joint promotes gas formation. If the molten weld metal cools slowly and allows all gas to rise to the surface before solidification, the weld would be virtually free of porosity. Isolated or uniform porosity: The cause of this form of singular porosity is generally faulty welding technique or defective material or both. Cluster or group porosity: Is a localised group of pores that may result from improper initiation or termination of the welding arc. Linear porosity: Always forms a straight line along a run of weld and is caused by gas evolving from contaminants.
Overlap.	(Cold lap/roll over.) Usually caused by incorrect manipulation of welding procedures i.e. low current combined with wrong travel speed. This defect can occur on the fusion face as well as the cap run if the fusion face contains tightly adhering oxides. (This would only be detected by NDT and probably interpreted as lack of fusion.) Overlap may be defined as a surface connected discontinuity that forms a severe mechanical notch parallel to the weld axis.
Tungsten Inclusion.	Particles of tungsten trapped in the weld metal deposited with the TIG process. Usually occurs when the operator dips the tungsten electrode tip into the molten pool. A second reason for this defect, not generally recognised, is that if the operating current is set too high the electrode tip will melt and droplets of tungsten will be fired into the molten pool by the shielding gas.

SPECIFIC CAUSES AND REMEDIES.

<u>Porosity.</u>

CAUSE	REMEDY
Excessive hydrogen, nitrogen or oxygen in welding atmosphere	Use low hydrogen welding process; filler metals high in deoxidisers; increase shielding gas flow
High solidification rate	Use preheat or increase heat input
Dirty base metal	Clean joint faces and adjoining surfaces
Dirty filler wire	Use specially cleaned and packaged filler wire and store in a clean area
Improper arc length, welding current or electrode manipulation	Change welding conditions and techniques
Volatisation of zinc from brass	Use copper-silicon filler metal; reduce heat input

Galvanised steel	Use E7010 electrodes and manipulate the arc heat to volatilise the galvanised zinc ahead of the molten weld pool
Excessive moisture in electrode covering or on joint surfaces	Use recommended procedures for baking and storing electrodes; preheat the base metal
High sulphur base metal	Use electrodes with basic slagging reactions

Inclusions

Failure to remove slag	Clean surface and previous weld bead
Entrapment of refractory oxides	Power wire brush the previous bead
Tungsten in the weld metal	Avoid contact between the electrode and workpiece; use larger electrode
Improper joint design	Increase bevel angle of joint
Oxide inclusions	Provide proper gas shielding

Weld metal cracking

Highly rigid joint	Preheat; relieve residual stresses mechanically; minimise shrinkage stresses using back step or block welding sequence
Excessive dilution	Change welding current and travel speed; weld with covered electrode negative; butter the joint faces prior to welding
Defective electrodes	Change to new electrode; bake electrodes to remove moisture
Poor fit-up	Reduce root opening; build up the edges with weld metal
Small weld bead	Increase electrode size; raise welding current; reduce travel speed
High sulphur base metal	Use filler metal low in sulphur
Angular distortion	Change to balanced welding on both sides of joint

Crater cracking	Fill crater before extinguishing the arc; use a welding current decay device when terminating the weld bead

Base metal cracking

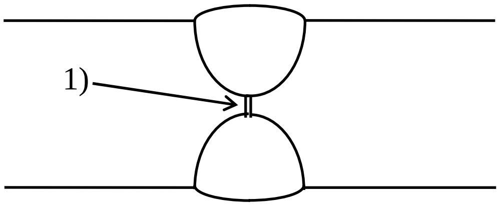
Hydrogen in welding atmosphere	Use low hydrogen welding process; preheat and hold for two hours after welding or post weld heat treat immediately
Hot cracking	Use low heat input; deposit thin layers; change base metal
Low ductility	Use preheat; anneal the base metal
High residual stresses	Redesign the weldment; change welding sequence; apply intermediate stress relief heat treatment
High hardenability	Preheat; increase heat input; heat treat without cooling to room temperature
Brittle phases in the microstructure	Solution heat-treat prior to welding

MACRO EXAMINATION

This section covers the interpretation of internal defects and their reporting with regard to the Macro examination.

During interpretation it is necessary to identify associated defects.

<u>example 1.</u>

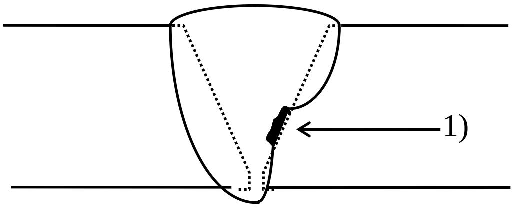


Report 1. Incomplete root penetration and root fusion.

In the above sketch incomplete root penetration can be seen but, because of the loss of penetration, incomplete root fusion is also present.
Planar defects such as incomplete sidewall, incomplete inter-run and incomplete root fusion are very often associated with the presence of a non metallic inclusion, typically slag for MMA and SAW and deoxidiser residue for MIG and TIG (ferritic steels).

<u>example 2.</u>

process MAG



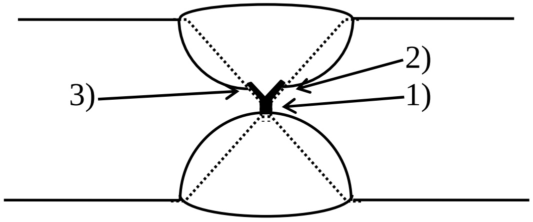
In this example incomplete sidewall fusion is present. Because the defect also has width it can largely be associated with a 'silica' inclusion.

report 1. Incomplete sidewall fusion with associated silica dioxide inclusion - add dimension.

The next sketch shows a root penetration / fusion defect caused because of either insufficient root gap or no back gouging. On examination incomplete sidewall fusion has resulted because of poor access.

<u>example 3.</u>

process MMA



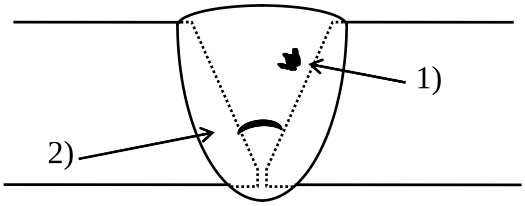
report 1. Incomplete root penetration and root fusion.
2. Incomplete sidewall fusion. *
3. Incomplete sidewall fusion. *

* Your judgement will be necessary in order to determine any associated inclusion.

As previously mentioned, slag and silica inclusions are associated with specific processes. With regard to interpretation the inspector must confirm the welding process in order to make an accurate assessment. This may be by reference to the welding procedure or by assessment of the weld face. Slag inclusions will be clearly volumetric against silica inclusions that will have length and limited width.

<u>example 4.</u>

Slag inclusions or silica inclusions?



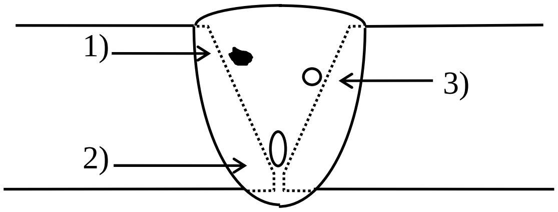
report 1. Slag inclusion.
2. Silica inclusion. (incomplete interpass fusion may also be present)

In general terms, slag inclusions are non-uniform in their shape; also very often the slag is still visible.

Gas inclusions, on the other hand, are generally uniform in their shape and are of a metallic appearance.

<u>example 5.</u>

Gas inclusions (pores), porosity or solid inclusions?

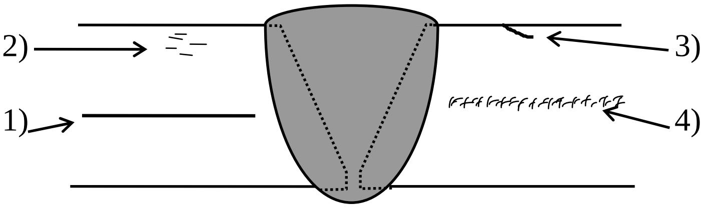


report 1. Slag inclusion.
2. Elongated gas cavity. } dimensions required.
3. Gas pore.

The inspector should report any parent metal defects - laps, laminations and segregation bands.

<u>Example 6.</u>

Parent metal defects.



Report 1. Laminations (straight and narrow).
2. Laminar inclusions (small, straight and narrow).

3. Laps (near surface of material).
4. Segregation bands (similar to lamination but lacks definite edges - hazy).

MACRO EXAMINATION

The report for the Macro should include:

Macro identification, material, welding process, sentencing standard.
All internal defects with type size and accept/reject.
All surface defects with type, size and accept/reject.
Geometric defects (e.g. misalignment) with type size and accept/reject.
Name, signature and date.

All defects should be arrowed and numbered on the report. For CSWIP the sentencing standard is ISO 5817 level B (stringent).

NON DESTRUCTIVE TESTING

ULTRASONIC INSPECTION

Type of operation:

Manual or mechanised.

Equipment:

Main unit comprising pulse generator, display oscilloscope, probe (chosen to suit work).

Mode of operation:

A pulse of electrical energy is fed to the probe in which a piezo-electric crystal converts it to mechanical vibrations at an ultrasonic frequency. The vibrations are transmitted (via a layer of grease to exclude the air) through the work. If they encounter a defect some are reflected back to the probe, where they regenerate an electrical signal. A cathode ray tube trace, started when the original signal is sent, displays the reflected defect signal and from it time - indicating distance from probe, and amplitude - indicating defect size, can be calculated.

Materials.

Most metal except those with coarse or varying grain structure.

Typical welding applications.

Welds in thick wall vessels.
Welds with access to one side only.

Operating parameters.

Probe frequency	1 - 5MHz
Portability	Good
Access	Good (can be battery operated)
Thickness range	5 - 500mm
Minimum defect size	5mm wide

Overall advantages.

Immediate presentation of results.
Not necessary to evacuate personnel.
Can be battery powered.
Depth location of defects.

Overall limitations.

Trained and skilled operator needed.
No pictorial record.

Safety.

Moderate care needed as for all electrical equipment.

MAGNETIC PARTICLE INSPECTION

Type of operation.

Manual or mechanised.

Equipment.

Power supply. Contacts or coil. Ultra-violet lamp (optional). Portable or fixed installation.

Mode of operation.

The work is magnetised either by passing a current through it, or through a coil surrounding it. Defects on or near the surface disrupt the magnetic field (unless they are parallel to it). A magnetic particle fluid suspension is applied which concentrates around the defects. The work is viewed either directly or by ultra-violet light using a dye which fluoresces - i.e. emits visible light (this must be done where normal lighting is subdued). After testing, work may be demagnetised if required.

Materials.

Magnetic materials only - ferritic steels and some nickel alloys.

Operating parameters.

Current	500 - 10,000 Amps (AC or DC)
Supply load	1 - 100 kVA
Portability	good
Access	restricted
Minimum defect size	0.025mm wide at surface
Testing time	10 - 80 seconds

Typical welding applications.

Rapid inspection of welded structural details.
Production rate inspection of small components.

Overall advantages.

Direct indication of defect location.
Initial inspection by unskilled labour.
Some indication of sub-surface defects but of low sensitivity.
Not critically dependent on surface condition.

Overall limitations.

No use for non-magnetic materials.
Defect detection critically dependent on alignment across magnetic field.
Sub-surface flaws require special procedures.

Safety

Moderate care needed in handling electrical equipment and flammable fluids.

RADIOGRAPHY

Gamma Radiography.

Type of operation.

Static - development may be mechanised.

Equipment.

Radioactive isotope in storage container. Remote handling gear. Lightproof cassette. Photographic development facilities. Darkroom and illuminator for assessment.

Mode of operation.

Gamma rays, similar to X-rays but of shorter wavelength, are emitted continuously from the isotope. It cannot be ‘switched off’ so when not in use, it is kept in a heavy storage container that absorbs radiation. They pass through the work to be inspected. Parts of the work presenting less obstruction to gamma rays, such as cavities or inclusions, allow increased exposure of the film. The film is developed to form a radiograph with cavities or inclusions indicated by darker images. Section thickness increases (such as weld) appear as less dense images.

Operating parameters.

Wavelength of radiation	0.001 - 0.015 nm 0.01 - 1 nm (1.25MeV - 80KeV)
Portability	good (except for container)
Access	good
Exposure time	1 second - 24 hours
Thickness range	up to 250 mm
Minimum defect size	1% of thickness

Materials.

Most weldable materials can be inspected.

Typical welding applications.

Site inspection.

Panoramic exposure for small work.

Advantages, limitations, consumables and safety as for X-ray radiography.

X-ray Radiography.

Type of operation.

Static or transportable.

Equipment.

X-ray tube. Stand and control gear. Lightproof cassette. Photographic development facilities. Dark room and illumination for assessment.

Mode of operation.

X-rays are emitted from the tube and pass through the work to be inspected. Parts of the work presenting less obstruction to X-rays, such as cavities or inclusions, allow increased exposure of the film. The film is developed to form a radiograph with cavities or inclusions indicated by darker images. Section thickness increases (such as weld under-bead) appear as less dense images.

Operating parameters.

Tube voltage	10 - 500 kV
Tube current	10 - 250 mA
Power consumption	1 - 10 kW
Portability	fair
Access	fair
Exposure time	1 sec - 10 min
Thickness range	up to 100 mm
Minimum defect size	0.1% of thickness X 0.05 mm

Materials.

Most weldable materials may be inspected.

Typical welding applications.

Pipelines
Pressure vessels.

Overall advantages.

Accurate pictorial presentation of results.
Radiographs may be kept as a permanent record.
Not confined to welds.

Overall limitations.

Personnel must be clear of area during exposure.
Cracks parallel to film may not show up.
Film expensive.

Consumables.

Film.
Processing chemicals.
Water.
Isotope replacements - for gamma radiography

Safety

Cumulative radiation risk to personnel requires stringent precautions.

DYE PENETRANT INSPECTION

Type of operation.

Manual or mechanised.

Equipment.

Minimum - aerosols containing dye, developer, cleaner.
Maximum - Tanks, work handling gear, ultra-violet lamp.

Mode of operation.

A special dye is applied to the surface of the article to be tested. A suitable time interval allows it to soak into any surface defects. The surface is then freed from surplus dye and the dye in the crack revealed by either: applying a white powder developer into which the dye is absorbed producing a colour indication,
or, illuminating with ultra-violet light under which the dye fluoresces, that is, emits visible light. This must be done where normal lighting is subdued.

Operating parameters.

Portability	excellent (for aerosols)
Access	good
Minimum defect size	0.025 mm wide
Time	30 minutes approx.

Materials.

Any - non porous.

Typical welding applications.

Root runs in pipe butt welds.
Leak paths in containers.

Overall advantages.

Low cost.
Direct indication of defect location.
Initial examination by unskilled labour.

Overall limitations.

Surface defects only detected.
Defects cannot readily be rewelded due to trapped dye.
Rough welds produce spurious indications.

Safety.

Dye and propellant gases have low flash points.

REPAIR BY WELDING

INTRODUCTION

The repair of defects that occur during welding ranges from simple welding operations to improve weld profile to extensive metal removal and subsequent welding to rectify extensive cracking. Repair of fabrication defects is generally easier than repair of service failures because the welding procedure used for fabrication may be followed during repair. The repair of service failures may be difficult because access may be hazardous and the welding procedures used for the original fabrication may be impossible to apply.

This section considers the procedures and the underlying metallurgical principles for the repair of carbon and alloy steels, wrought and cast iron, and some non-ferrous alloys.

Types of defects.

Defects requiring repair can be divided into two categories.

1. Fabrication defects.
2. Service failures.

FABRICATION DEFECTS.

The commonest defects that occur during the making of a weld include porosity, slag inclusions, undercut, lack of fusion, incomplete penetration and solidification cracking. Defects that can occur during welding but which may not appear until up to 48 hours after welding are hydrogen induced cracking and lamellar tearing of the parent metal.

Repair by welding involving removal of defective areas and replacement by sound material can cost up to ten times as much as depositing similar quantities of weld metal correctly in the first place. Therefore it is important to avoid unacceptable defects and it can be an economic proposition in many cases to carry out fairly large scale procedure tests before fabricating critical components. Having taken all possible precautions to meet acceptance standards, defects inevitably occur, especially when welding is carried out manually rather than by a mechanised method. To judge whether compliance with the requirements of a code of practice have been met, it is necessary to be able to detect any defects by non-destructive testing and also to determine their dimensions and orientation. Codes recognise that flawless welds are almost impossible to obtain and various levels of acceptance are laid down in respect of allowable defects - porosity, inclusions etc. Planar defects such as cracks or lack of fusion may nearly always be prohibited and the normal procedure is to repair the welds, followed by re-inspection.

The repair procedure may be very simple and merely require the deposition of more weld metal to rectify undercut but the repair of deep-seated defects such as lamellar tearing can entail extensive excavation and rewelding. The welding procedure for the repair weld can often be very similar to the original welding in respect to preheat, type of consumable and welding conditions. However if cracking is present the welding conditions may have to be changed to avoid this defect in the repair weld. There are cases in which fabrication defects are not discovered until final inspection and if a sub-section originally welded in the flat position is incorporated into a large structure it is possible that repairs may have to be carried out in less favourable welding positions such as vertically or overhead.

In critical components the repair procedure may have to be qualified by procedure tests particularly if fracture test requirements are specified.

In cases where extensive rectification would be required to meet code requirements, experience has shown that considerable savings in both cost and time can be obtained if the significance of the defects present is assessed on a fitness for purpose basis. This involves calculation of the maximum growth of defects under fatigue loading and the required toughness levels of weld metal, parent plate and HAZ to avoid brittle fracture during the peak loadings of a structure. The application of fitness for purpose criteria has in some cases resulted in some inspection authorities accepting defects that exceed the limits of code requirements.

SERVICE FAILURE

Service failure, in the context of this section, consists of cracks caused mainly by fatigue, brittle fracture, stress corrosion or creep. In some cases plant shutdown may be necessary immediately a crack is discovered if, for example, it is found by leaking of a containment vessel, the crack having propagated from inside through the vessel wall. In some rare cases a fatigue crack will relieve the stresses in a highly stressed area and will run out of steam and can be left without repair. In other cases fatigue crack growth can be monitored by periodical inspection until plant shutdown for repair is convenient.

Brittle fracture is fortunately a relatively rare occurrence compared with fatigue, but when it occurs it can be far more spectacular leading to disasters such as the breaking in half of ships, or the fragmentation of pressure vessels. Whether repair is feasible depends on the proportion of the structure remaining intact, and repair can range from removal of the cracked area and welding, to the pre-fabrication of new sub-sections, which are welded into place. The latter expedient is considered to be rebuilding rather than repair.

The repair of service cracks may be difficult for one or all of the following reasons:

1. Access may be restricted. e.g. inside a mine winder.
2. Preheat and / or post weld heat treatments may be difficult or even impossible to apply. e.g. because of risk of damage to machined surfaces, plastic seals, electrical insulation etc. or the presence of flammable materials.
3. The component cannot generally be rotated into the most convenient position for welding. Therefore potential welding may have to be used. e.g. circumferential seams of a pressure vessel may have to be repaired in the overhead position by manual welding whereas the vessel was originally fabricated by rotating it under a SAW machine. The change in welding process and position of welding could affect the fracture toughness. Therefore complex weld procedure tests may be required for the repair of critical items of plant.
4. The environment may be hazardous. e.g. heat, nuclear radiation, underground.

GENERAL TECHNIQUES FOR TYPICAL REPAIRS

Metal Removal.

The defect may be in a single run fillet weld requiring only a small amount of metal to be removed or it may be a large crack extending deep into parent metal.

For removing metal rapidly the most convenient method is air arc gouging in which the metal is melted by a carbon arc and is blown out of the cut by a stream of compressed air, which passes through holes in a specially designed electrode holder. Arc-air gouging can be used on both ferrous and non-ferrous metals but the surface finish is generally not as good as obtained by oxyacetylene gouging and the gouged surface finish allows the use of non-destructive testing by dye penetrant or magnetic particle inspection to check if defects have been completely removed.

Other thermal methods of metal removal, less commonly used, are oxygen-arc or oxyacetylene gouging. Mechanical methods include pneumatic chisels, high-speed rotary tungsten carbide burrs and grinding wheels.

Groove shape.

The minimum amount of metal should be removed for economic reasons but is necessary to produce a groove wide enough for access and manipulation of the welding electrode or filler wire. Widths may have to be increased if a repair involves welding in the overhead position or if the surface of the groove has to be buttered with a layer of weld metal of one composition before filling the groove with weld metal of a different composition to prevent weld metal cracking.

While it is more common to carry out repair with weld metal of one composition only, it may still be advantageous to use the buttering technique particularly in large grooves to reduce the effect of shrinkage across the joint. Each layer of weld metal has a larger free surface than it would if the weld consisted of horizontal layers as in normal fabrication practice and this allows contraction to take place freely with minimum strain on the parent metal. This reduces the risk of cracking in the weld or the HAZ and also reduces the tendency for distortion of the component.

WELDING PROCESSES

The fusion welding processes commonly applied to repair welding are as follows:

1. Manual metal arc welding with flux coated electrodes.
2. Flux cored arc welding with coiled tubular electrodes, either gas shielded or self-shielded.
3. MIG welding with coiled solid wire and inert shielding gas.
4. MAG welding with coiled solid wire and active shielding gas.
5. TIG welding with a non-consumable tungsten electrode and a separately fed filler wire.
6. Oxyacetylene welding.

For most ferrous alloys MMA welding is the preferred repair method because of its adaptability to difficult situations where access may be restricted, the angle of inclination to the workpiece not being as critical as that of a welding gun in the semi-automatic MIG or MAG processes.

Flux cored arc welding is used extensively in steel foundries for repair of castings which can be positioned so that welding can be carried out in the flat position in which maximum welding current and deposition rates can be used.

MIG welding is generally favoured for non-ferrous materials and is the first choice for welding aluminium alloys because of the ease of MIG welding aluminium compared with MMA welding and for high welding quality.

SUMMARY

Before a welding repair is carried out the need for repair must be carefully considered. If a component or structure contains defects of a known size, whether these are fabrication or service defects, a fitness for purpose evaluation may show them to be insignificant, thus saving the cost of repair. The time required to undertake a repair is another factor that must be taken into consideration.

When a repair is shown to be necessary, the factors to be considered include the following:

1. The extent of the repair and possible consequences such as distortion.
2. The access for welding and welding position.
3. Requirements for preheat and / or post heat.
4. Choice of welding consumables and welding procedure to avoid pre or post weld heat treatment.
5. The mechanical properties required in the weld metal and HAZ and the need for procedure tests.

Considerations during a repair:

1. Repair procedure.
2. Welders qualified to repair procedure.
3. Repair correctly identified and marked.
4. Type of excavation. (gouging / grinding)
5. Monitoring removal.
6. Shape of excavation.
7. NDT on excavation.
8. Monitoring rewelding.
9. NDT on repaired area (as per original NDT)

Having suitable welding procedures and fulfilling the metallurgical requirements are the first two factors for a successful repair.

The third factor is a high level of welder and supervisory skill because the application of the first two factors under the difficult conditions under which some complex repairs are carried out depends on the expertise of these personnel.

CONSUMABLES

Welding consumables are:

- Electrodes.
- Wire (lengths or rolls).
- Fluxes.
- Gases.

Each consumable is critical in respect to:
Specification / supplier. Condition. Treatment (if any).

Take for example a common MMA covered electrode. This will be to a specified type but an additional requirement may be that only one or two suppliers / manufacturers are acceptable. The electrode must be in good condition with regard to corrosion and mechanical damage and so storage and mechanical handling are important. If the electrode requires heat treatment for low hydrogen potential then the temperature, time and oven condition require attention. The issue of electrodes to the welder for use and the procedures for recycling and scrap must be dealt with care.

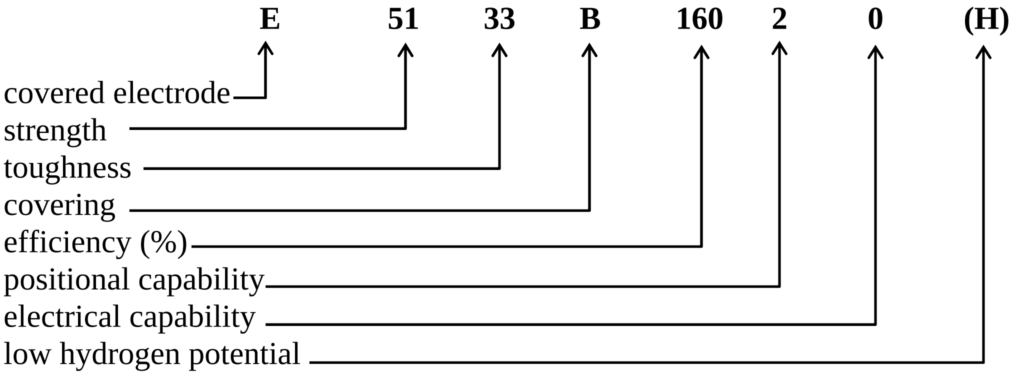
There are many codes in existence that cover the various consumables. The only reasonable rule is to keep to what is specified unless (and only unless) a written order for variation is received.

IDENTIFICATION OF ELECTRODES

BS 639.

In the BS system (standard BS 639: 1986) for carbon and carbon manganese steels the electrode may be partially or completely specified by a letter or number.

For example an electrode may be specified thus:



The first four parts of the code are compulsory, comprising:

E	covered electrode
51	Strength
33	Toughness
B	Coating

(The essentials are “S T C “- strength, toughness, covering)

The details for each factor are as follows:

First group - strength.

Electrode designation.	E43	E51
Tensile strength - N/mm2	430 - 550	330
Minimum yield stress - N/mm2	510 - 650	380

Second group - toughness.

First digit.	0	1	2	3	4	5
Temperature for impact value of 28 J, ° C.	not specified	+20	0	-20	-30	-40

Second digit	0	1	2	3	4	5	6	7	8
Temperature for impact value of 47 J, ° C.	not specified	+20	0	-20	-30	-40	-50	-60	-70

Covering.

B	Basic
BB	High efficiency
C	Cellulosic
O	Oxidising
R	Rutile (medium coating)
RR	Rutile (heavy coating)
S	other types

Efficiency.

% recovery to the nearest 10 % (≥ 110)

Positional Capability.

1	all positions
2	all positions except vertical down
3	flat and, for fillet welds, horizontal vertical
4	flat
5	flat, vertical down, and for fillet welds horizontal vertical
9	any position or combination of positions not classified above

Electrical capacity.

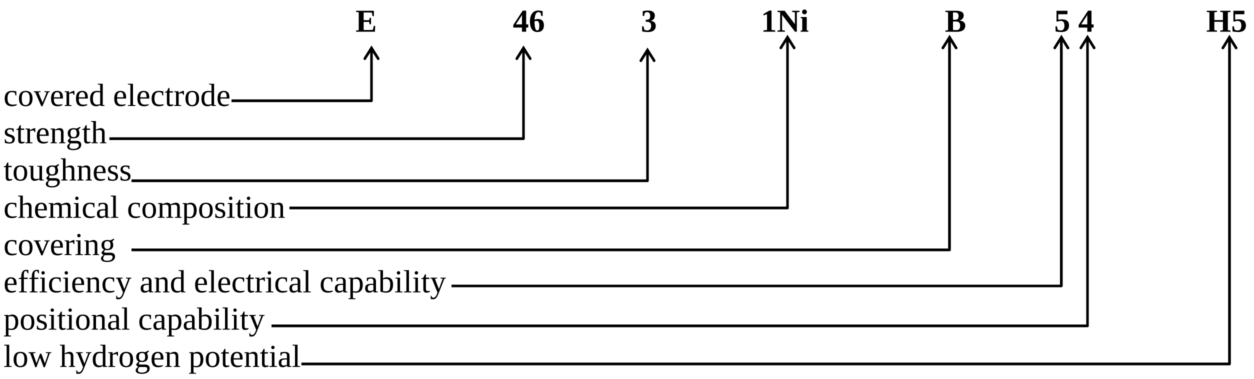
Code.	0	1	2	3	4	5	6	7	8	9
DC recommended electrode polarity.	as recommended by manufacturer	+/-	-	+	+/-	-	+	+/-	-	+
AC minimum open circuit voltage.	not suitable for use on AC	50	50	50	70	70	70	80	80	80

Low hydrogen potential.

Indicates hydrogen control (≤ 15 ml / 100g)

EN 499.

The identification of covered electrodes in EN 499 is as follows:



E 46 3 1Ni B 5 4 H5

covered electrode
strength
toughness
chemical composition
covering
efficiency and electrical capability
positional capability
low hydrogen potential

covered electrode.

strength.

Symbol	minimum yield strength (N/mm2)	tensile strength (N/mm2)	minimum elongation
35	355	440 - 570	22 %
38	380	470 - 600	20 %
42	420	500 - 640	20 %
46	460	530 - 680	20 %
50	500	560 - 720	18 %

toughness.

Symbol	Z	A	0	2	3	4	5	6
Temperature for minimum average impact energy of 47 J, °C	no requirement	+20	0	-20	-30	-40	-50	-60

chemical composition.

Symbol	none	Mo	MnMo	1Ni	2Ni	3Ni	Mn1Ni	1NiMo
% Mn	2.0	1.4	>1.4-2.0	1.4	1.4	1.4	>1.4-2.0	1.4
% Mo	-	0.3-0.6	0.3-0.6	-	-	-	-	0.3-0.6
% Ni	-	-	-	0.6-1.2	1.8-2.6	>2.6-3.8	0.6-1.2	0.6-1.2

Z = any other agreed composition.

covering.

A	acid covering
C	cellulosic covering

R	rutile covering
RR	rutile thick covering
RC	rutile cellulosic covering
RA	rutile acid covering
RB	rutile basic covering
B	basic covering

efficiency.

Symbol	1	2	3	4	5	6	7	8
Weld metal recovery %	≤105	≤105	>105≤125	>105≤125	>105≤160	>105≤160	>160	>160
Type of current	AC+DC	DC	AC+DC	DC	AC+DC	DC	AC+DC	DC

positional capability.

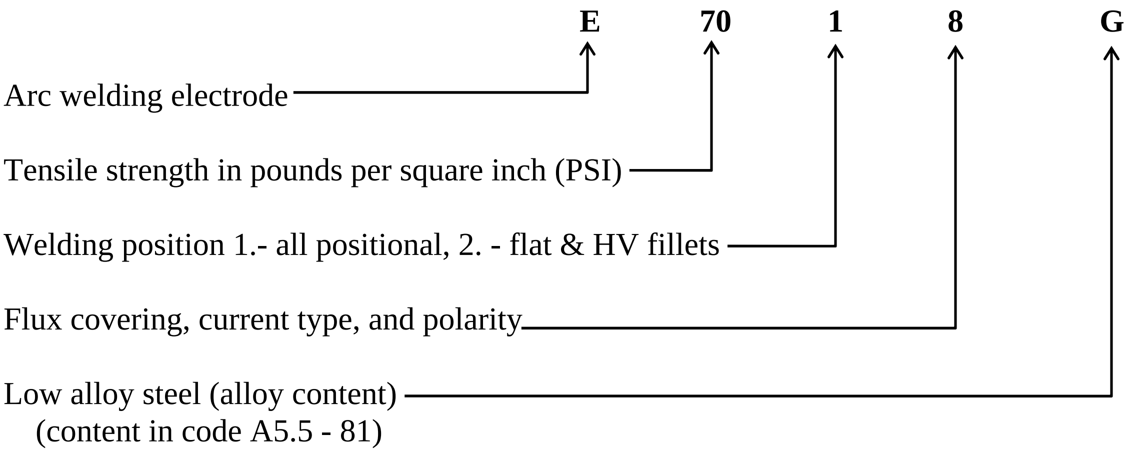
1. all positions
2. all positions except vertical down
3. flat butt weld, flat fillet weld, and horizontal vertical fillet weld
4. flat butt weld, flat fillet weld
5. vertical down and positions according to 3.

low hydrogen potential.

Symbol	H5	H10	H15
hydrogen content ml / 100g	5	10	15

AMERICAN WELDING SOCIETY.

Identification for manual metal arc welding consumables for carbon and carbon/manganese steels A5. 1 - 81



ELECTRODES.

Rutile electrode.

A general purpose electrode, which gives the best appearance and is easy to use.

Drying - easy. 100° C for one hour and stored at ambient for shelf life.

Basic electrode.

Low hydrogen applications.

Drying - bake at 450° C for one hour and store at 150° C for shelf life (in a calibrated oven).

Issue - issued in small batches in heated quivers (70° C).
rebake or discard after use.
record number of rebakes, normally three times only.

N.B. There is the option of vacuum packed electrodes, which have a time limit when opened.

Cellulosic electrode.

Usually used in stovepipe welding (vertical down).

High hydrogen, therefore high voltage, therefore high penetration.

No drying required, store in dry conditions.

Electrode Checks.

Size -	diameter, length, quantity.
Type -	specification, grade, tradename.
Condition -	flux damage.

The electrode core wire is ideally similar in composition to the parent material, though generally the electrode wire is similar in composition to mild steel.

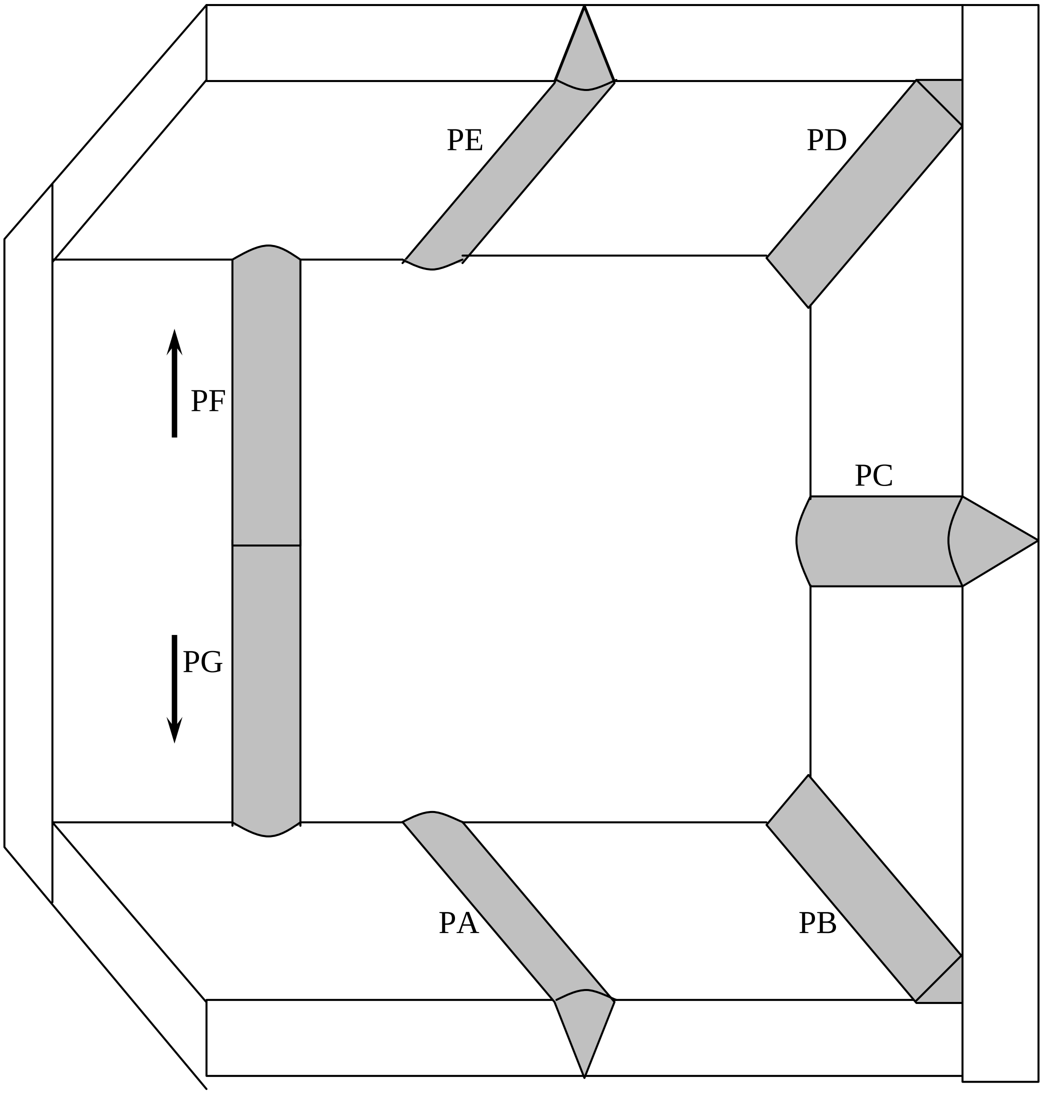
FLUX.

The flux has a wide range of properties and uses including:
adding elements to the weld pool
shielding the weld pool (protective slag covering)
stabilising and shielding the arc
the protective slag controls and slows cooling
gives appearance characteristics to the finished weld
aids in ignition
directs the arc
shielding of solidification
fluxing (cleaning) action
helps support weld (i.e. a viscous flux)
aids in metal recovery

WELDING POSITIONS

The easiest position for welding is the flat or downhand position. Any deviation from this position, other than small deviations in slope makes successful welding much more difficult. This is because gravity does not help in positioning of the weld metal.
Positional welding (other than flat) often relies on arc force and surface tension effect; therefore the welding position may affect the mechanical properties of the weld and the likelihood of defects.
For simplicity the various welding positions are coded as shown below.

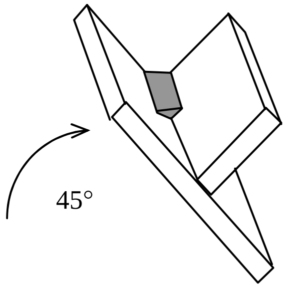
<u>BS 499 Welding Positions.</u>



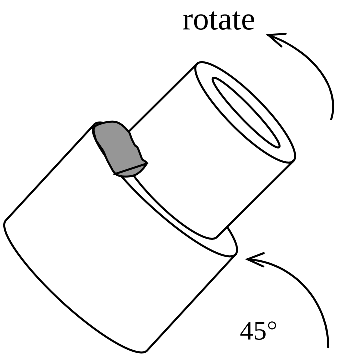
PA	Flat.
PB	Horizontal vertical.
PC	Horizontal.
PD	Horizontal overhead.
PE	Overhead.

PF	Vertical up.
PG	Vertical down.

ASME Welding Positions.



1F



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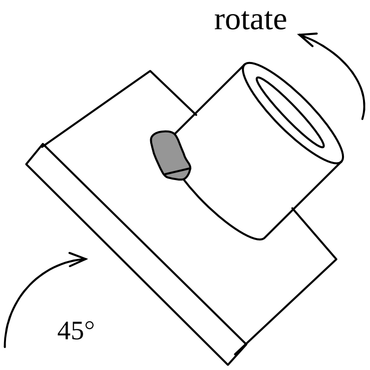

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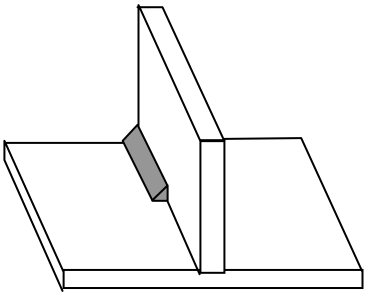

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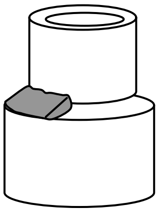

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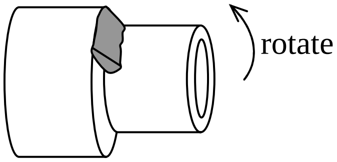
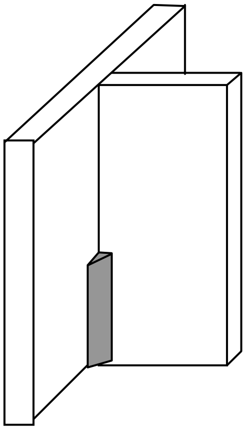
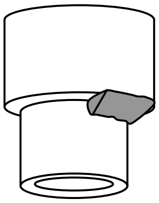


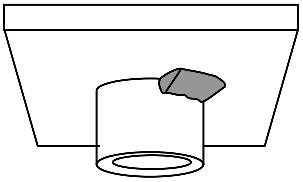
2FR



3F



4F



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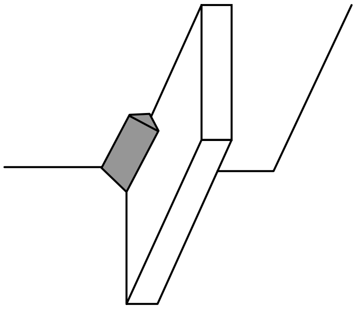
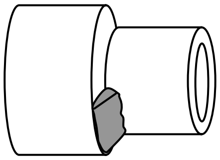
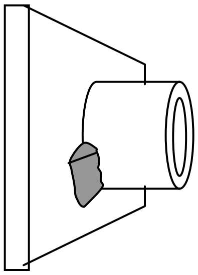
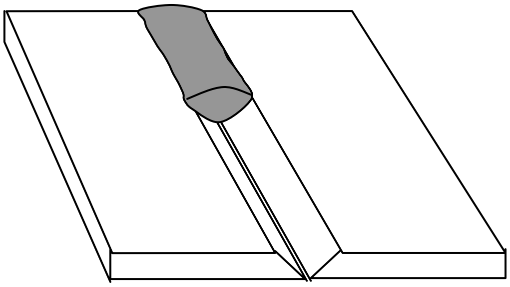


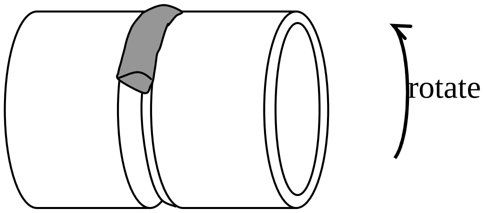




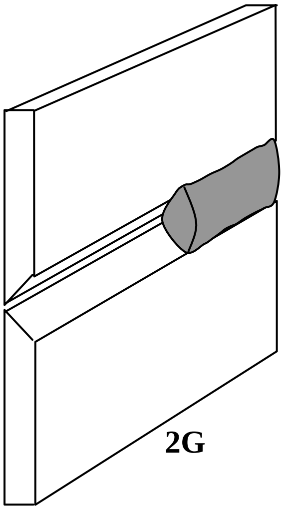
4F **5F** **5F**

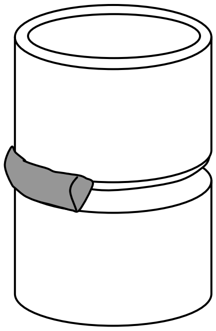
FILLET WELDS



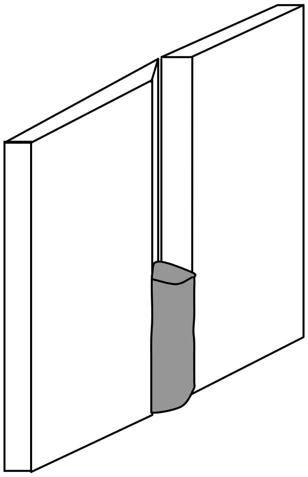


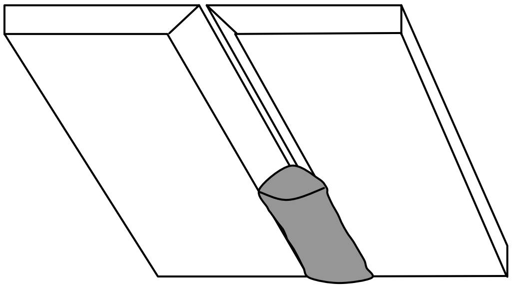
1G **1G**



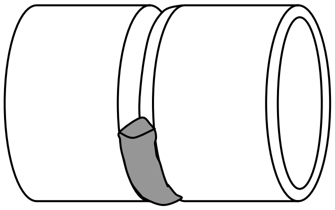


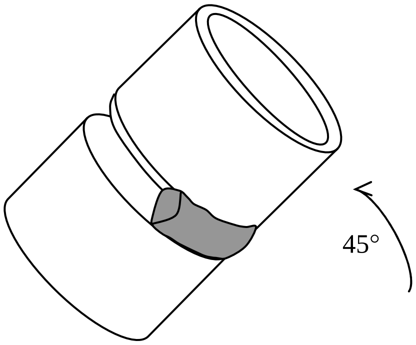
2G **2G**





3G **4G**



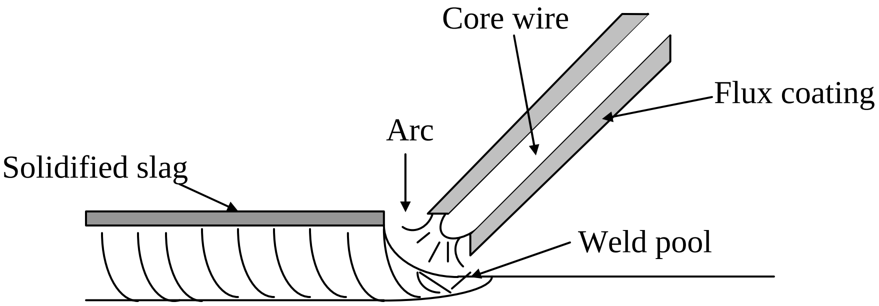


5G **6G**

BUTT WELDS

MANUAL METAL ARC WELDING

Manual metal arc (MMA) welding, also known as shielded metal arc welding (SMAW), stick, and electric arc welding is a constant current drooping arc process.
(The arc process is divided into two types – drooping and flat. This refers to their volt-amp output characteristics. By using a drooping characteristic, an alteration in arc length gives a very small change in current.)
In manual metal arc welding the heat source is an electric arc, which is formed between a consumable electrode and the parent plate. The arc is formed by momentarily touching the tip of the electrode unto the plate and then lifting the electrode to give a gap of 3 mm – 6 mm between the tip and the plate. When the electrode touches the plate, current commences to flow and as it is withdrawn the current continues to flow in the form of a small spark across the gap, which will cause the air in the gap to become ionised, or made conductive. As a result of this the current continues to flow even when the gap is quite large. The heat generated is sufficient to melt the parent plate and also melt the end of the electrode – the molten metal so formed is transferred as small globules across the arc into the molten pool.



Type of operation.

Manual.

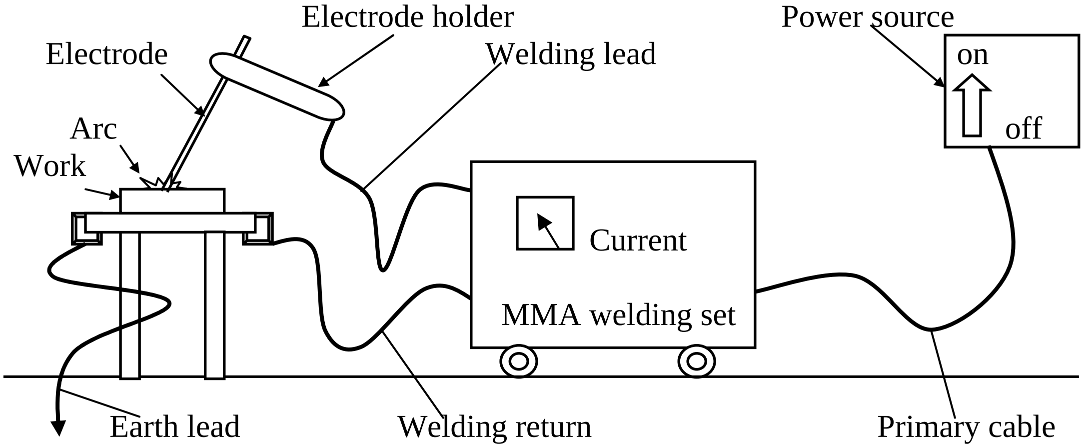
Mode of Operation.

Arc melts parent plate and electrode to form a weld pool that is protected by the flux cover. Operator adjusts the electrode feed rate, i.e. hand movement, to keep the arc length constant. Slag must be removed after depositing each bead. Normally a small degree of penetration, requiring plate edge preparation. Butt welds in thick plate, or large fillets are deposited in a number of passes. The process can also be used to deposit metal to form a surface with alternative properties.

Equipment.

Welding Sets.
Manual metal arc sets are manufactured in a range of sizes, usually distinguished by current – note the duty cycle at which the current is quoted when comparing sets. Engine powered generators allow operation away from mains supplies.

Electrical input is single-phase at 240 volts for smaller sets, and 415 volts (2 live phases of a three-phase supply) for larger sets.
Output is AC or DC. AC only sets need an open circuit voltage of 80 volts to run all electrodes. 50 volts is safer and allows more current to be drawn, but is limited to general purpose rutile electrodes only.
A control on the set adjusts current – the current is shown either on a simple scale, or for accurate work, on a meter.



Power Source.

The welding machine consists of a power source with welding lead and an electrode holder. The function of the power source is to provide the voltage necessary to maintain an arc between the workpiece and the end of the electrode. The amount of current provided by the power source can be altered by a control to suit different welding conditions. Power source may supply direct current or alternating current to the electrode. AC transformers and DC generators supply only one type of current, but transformer-rectifiers can be switched between AC and DC output.

Welding Cables.

The welding current is conducted from the power source to the work by multi-strand, insulated flexible copper or aluminium cables. A return cable is required to complete the welding circuit between the work and the power source. The size of the cable must be sufficient for the maximum output of the welding power source. The earth cable is a third cable, which acts as a safety device in the event of an electrical fault.

Electrode Holder.

The holder should be relatively light, fully insulated and rated for at least maximum power source output.

Return Clamp.

This is fastened to the work or bench on which the work is placed and completes the welding circuit. The surface clamped should be clean enough to allow good metal-to-metal contact.

Welding Shield or Helmet.

A welding shield or helmet is necessary for protection from arc ray and heat, and the spatter from the molten metal. The arc is viewed through a filter that reduces the intensity of the radiation, but allows a safe amount of light to pass for viewing the weld pool and the end of the electrode.

Characteristics.

Electrical

D.C. – More portable, used for shop and site applications. Safer with a lower open circuit voltage ≈ 50 volts.
D.C.E.P. – (electrode positive) Gives deep penetration. Used for fillet welds, fill + cap passes
D.C.E.N. – (electrode negative) Gives shallow penetration. Used for 'open root' butts.
A.C. – Shop applications. Open circuit voltage ≈ 80 volts.

Welding Variables.

Volts – Controls arc length and shape of the weld.
Amps – Controls penetration.
Run out length – Controls travel speed.
Together the above three main welding parameters control heat input.
Electrode Angles – Slope affects penetration. Tilt should bisect the angle of the joint.

Principal Consumables. (Electrodes)

Basic – Low hydrogen potential. Used on 'critical' welds.
Rutile – For general purpose non-critical applications.
Cellulosic – High in hydrogen. Used for vertical down 'stovepipe' welding.
Iron Power – High deposition in flat and HV positions. Toughness may suffer.

Applications.

Pipelines
Nozzles and nodes.
Medium and heavy fabrications.
Site applications.

Effect Of Variation In Procedure.

Arc too short.

Too short an arc length will cause irregular piling of the weld metal. The ripples will be irregular in height and width.

Arc too long.

Too long an arc length will cause the deposit to be course rippled and flatter than normal. The ripples will be evenly spaced and the stop-start crater flat and blistered.

Travel too slow.

A slow rate of travel gives a wider, thicker deposit, shorter than normal length. Too slow a rate of travel may allow the slag to flood the weld pool causing difficulty in controlling deposition. The ripples will be course and evenly spaced, the stop-start crater flat.

Travel too fast.

A fast rate of travel gives a narrower, thinner deposit, longer than normal length. Too fast a rate of travel may prevent adequate interfusion with the parent metal. The ripples will be elongated and the stop-start crater porous.

Current too low.

A low welding current tends to cause the weld metal to pile up without adequate penetration into the parent metal. Too low a welding current makes the slag difficult to control. The ripples will be irregular with slag trapped in the valleys and the stop-start crater irregular.

Current too high.

A high welding current gives a deposit that is flatter and wider than normal with excessive penetration into the parent metal. Too high a welding current causes considerable spatter. The ripples will be course and evenly spaced. The stop-start crater hollow and porous.

Correct procedure.

With correct arc length, rate of travel, welding conditions and technique, the run deposited metal will be regular in thickness and width, with a neat smooth finely rippled surface, free from porosity or any slag entrapment. The stop-start crater will be sound.

MMA Weld Defects and Causes.

Lack of fusion/penetration.

Too large an electrode for weld preparation.
Incorrect angle of electrode for weld preparation.
Current too low.
Travel speed too high.
Wrong polarity.
Poor incorporation of tack welds.
Incorrect joint preparation.
Arc too long.

Porosity.

Damp electrode.
Incorrect electrode for parent material.
Current too low.
Current too high.
Arc too long.
Ineffective filling of weld craters.
Bad weaving techniques.
Material condition. e.g. scale, oil, rust, damp, and paint.

Slag inclusion.

Travel speed too slow.
Electrode too large.
Inadequate inter-run cleaning.
Welding over irregular profiles.
Arc too long.
Variations in travel speed.

Joint configuration.

Undercut.

Current too high.
Excessive weaving.
Incorrect angle.
Excessive travel speed.

Spatter.

Current too high.
Arc too long.
Incorrect angle of electrode.

Other typical defects associated with MMA include:

Excess penetration.
Overlap.
Stray flash.
Crater cracks.

TUNGSTEN INERT GAS WELDING

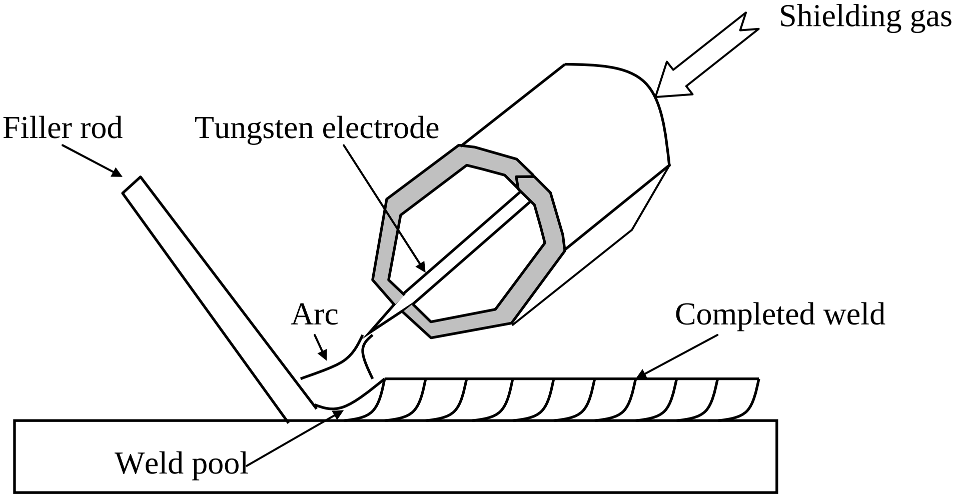
Tungsten inert gas welding is a constant current drooping arc process. It is also known as TIG, gas tungsten arc welding – GTAW, wolfram inert gas – WIG, and under the trade names of argon arc and heli arc.

Type of Operation.

Usually manual, but can be mechanised.

Mode of Operation.

An arc is maintained between the end of a tungsten electrode and the work. The electrode is not consumed and the current is controlled by the power source setting. The operator must control the arc length and also add filler metal if needed to obtain the correct weld; consequently, a high degree of skill is needed for the best results. The arc is unstable at low currents. Special provision is made for starting (high frequency or surge injection) and for welding thin materials (pulse TIG).



DC TIG.

In DC welding the electrode usually has negative polarity, which reduces the risk of overheating which may otherwise occur with electrode positive. The ionised gas or plasma stream can attain a temperature of several thousand degrees centigrade. Consequently within the normal range of welding currents (5 – 300 A) rapid cooling can be effected.
The TIG torch allows the electrode to extend beyond the shielding gas nozzle.
The arc is ignited to high frequency (HF) pulses, or by short circuiting the electrode to the workpiece and withdrawing at a present low current. In DC welding the arc is in the form of a cone, the size of which is determined by the current, the electrode diameter and the vertex angle. D.C.E.N. is used for all materials except aluminium and magnesium, usually using a thoriated or committed tungsten electrode.

AC TIG.

With AC the polarity oscillates at 50 Hz. The technique is used in welding aluminium and magnesium alloys, were the periods of electrode positive ensure efficient cathodic cleaning of the tenacious oxide film on the surface of the material. Compared with DC welding, the disadvantages of the technique lie in the low penetration capacity of the arc and, as the arc extinguishes at each current reversal, in the necessity for a high open circuit voltage (typically 100 V and above), or continuously applied HF, to stabilise the arc. Low penetration results in particular from the blunt or ‘balled’ electrode, which is caused by the high degree of electrode heating during the positive half cycle. Where deep penetration is required, use of DC with helium as the shielding gas, which does not suffer from these disadvantages and is somewhat tolerant to surface oxide, may be an alternative. Use of helium, however is not particularly attractive because of its high cost and, in the absence of the cleaning action of the arc, the weld pool/parent metal boundaries can be somewhat indistinct, thus making it difficult to monitor and control the behaviour of the weld pool. AC uses a zirconiated tungsten flat tip electrode. Starts can be scratch, lift or high frequency – HF being the best.

Welding Variables.

Amperage	controls fusion and penetration.
Voltage	controls arc length.
Travel speed	controls depth of penetration.
Gas flow rate	protects weld from atmosphere.
Electrode extension	affects penetration.

Welding Sets.

Sets are manufactured in a range of sizes, identified by current. Also important is whether the output is DC only, DC/AC or AC only. AC is needed for most work on aluminium. Electrical input may be single phase at 240v or 415v, or three phase at 415v. On the normal DC or AC output an ‘HF unit’ superimposes a high voltage high frequency supply to cause a spark from electrode to parent metal when the welder wants to start the arc. Alternatively, an electronic control switches the current on just as the welder lifts the electrode off the work – ‘touch start’. The output has a drooping characteristic, so by switching off the HF unit it can be used for manual metal arc. Alternatively, an add-on HF unit can convert a manual metal arc set to TIG.

The welder often uses a foot switch wired to the set to switch on and off, and to give a fine control of current. ’Slow start’ and ‘current delay’ controls allow current to rise and fall slowly at the beginning and end of a weld, for example welding round a pipe. As for gas shielded metal arc sets a cylinder holder and/or a water cooling unit for use with heavier guns, may be built in.

Accessories include: welding return cable, connectors to set, clamps or clips, torch and connecting hose assembly to suit current (torch has its own built in lead to stand up to high frequency supply), gas hose, gas regulator, cylinder stand.

Electrode.

Selection of electrode composition and size is not completely independent and must be considered in relation to the operating mode and the current level. Electrodes for DC welding are pure tungsten or tungsten with 1 or 2% thoria, the thoria being added to improve electron emission which facilitates arc ignition. In AC welding, where the electrode must operate at a higher temperature, a pure tungsten or tungsten-zirconia electrode is preferred, as the rate of tungsten loss is somewhat less than with thoriated electrodes and the zirconia aids retention of the ‘balled’ tip.

In DC welding a small diameter, finely pointed (approximately 30°) electrode must be used to stabilise low current arcs at less than 20A. As the current is increased, it is equally important to readjust the electrode diameter and vertex angle. Too fine an electrode tip causes excessive broadening of the plasma stream, due to the high current density, which results in a marked decrease in the depth to width ratio of the weld pool. More extreme current levels will result in excessively high erosion rates and eventually in the melting of the electrode tip. Recommended electrode diameters and vertex angles in argon shielding gas for the normal range of currents are given below.

	DC ELECTRODE NEGATIVE		AC
Welding Current (A)	Electrode Diameter (mm)	Vertex angle (degrees)	Electrode Diameter (mm)
< 20	1.0	30	1.0 – 1.6
20 to 100	1.6	30 – 60	1.6 – 2.4
100 to 200	2.4	60 – 90	2.4 – 4.0
* 200 to 300	3.2	90 – 120	4.0 – 4.8
* 300 to 400	3.2	120	4.8 – 6.4

* Use current slope in to minimize thermal shock, which may cause splitting of the electrode.

DC electrode thoriated tungsten. AC electrode zirconiated tungsten with balled tip, electrode diameter depends on degree of balance on AC waveform.

Shielding Gas.

The shielding gas composition is selected according to the material being welded, and the normal range of commercially available gases is given below.

Metal	Argon	Argon +Hydrogen	Helium	Helium -Argon	Nitrogen	Argon-Nitrogen
Mild steel	●					
Carbon steel	●			o		
Low alloy steel	●			●		
Stainless steel	●	●	o	o		
Aluminium	●		● ●			
Copper	●		●	●	o	o
Nickel alloys	o	●		o		
Titanium and Magnesium	●		o			

● most common use o also used

The most common shielding gas is argon. Argon is cheaper and ionises more easily than helium. This is used for welding a wide range of material including mild steel, stainless steel and the reactive aluminium, titanium and magnesium.

Argon-hydrogen mixtures, typically 2% and 5% hydrogen, can be used for welding austenitic stainless steel and some nickel alloys. The advantages of adding hydrogen are that the shielding gas is slightly reducing, producing cleaner welds, and the arc itself is more constricted, thus enabling higher speeds to be achieved and/or producing an improved weld bead penetration profile, i.e. greater depth to width ratio. It should be noted that the addition of a hydrogen addition introduces the risk of hydrogen cracking (carbon and alloy steels) and weld metal porosity (ferritic steels, aluminium and copper), particularly in multipass welds.

Helium and helium-argon mixtures (typically 75/25 helium/argon) have particular advantages with regard to higher heat input. The greater heat input is caused by the higher ionisation potential of helium, which is approximately 25eV compared with 16eVfor argon. Helium gives faster welding speeds and deeper penetration (due to higher heat input).

As nitrogen is a diatomic gas, on re-association at the workpiece surface it is capable of transferring more energy than monatomic argon or helium. Hence its addition to argon can be particularly beneficial when welding materials such as copper, which have high thermal conductivity. The advantages of nitrogen additions cannot be exploited when welding ferritic and stainless steels because nitrogen pick up in the weld pool could cause a significant reduction in toughness and corrosion resistance.

The effectiveness of a gas shield is determined at least in part by the gas density. As the density of helium is one tenth that of helium, difficulties can be experienced in protecting the weld pool, particularly when welding in draughty conditions or at high currents, which may induce turbulence in the gas shielding system. Effective shielding can be maintained by increasing the gas flow – typically by a factor of two. Shielding of the weld pool can also be improved by use of a gas lens, which is inserted into the torch nozzle to ensure laminar flow. Adoption of this technique is strongly recommended when welding in positions other than the flat and for welding curved surfaces.

TIG Weld Defects and Causes.

Porosity.
- Gas flow too low or too high.
- Leaking gas lines.
- Draughty conditions.
- Electrode stick out from nozzle too long.
- Contaminated/dirty weld prep.
- Contaminated/dirty wire.
- Incorrect gas shield.
- Arc length too long.

Lack of Penetration
- Current too low.
- Root face too large.
- Root gap too small.
- Mismatched edges.
- Poor welder technique.
- Filler wire too large.
- Arc length too long.

Tungsten Inclusions.
- Poor technique.
- Incorrect shielding gas.

Lack of Fusion.
- Current too low.
- Poor technique.

Surface Oxidation.
- Insufficient gas shield while cooling.
- Insufficient purge on single sided roots.

Spatter.
- Arc length too long.
- Wrong shielding gas.

Crater Cracking.
- No slope out on current.
- Poor welder technique.

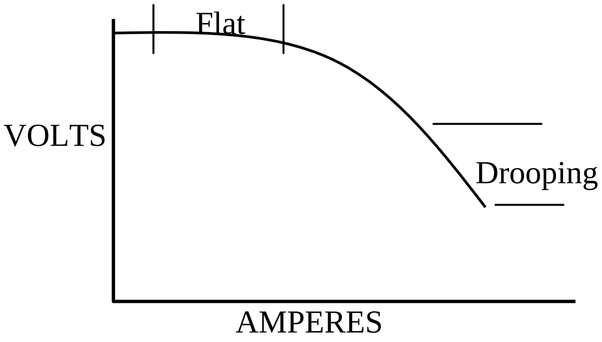
Other typical TIG defects include:
- Undercut.
- Burnthrough.
- Excess penetration.
- Unequal leg lengths.

Applications.
- Aerospace materials.
- Critical root runs in pipes.
- General light applications.
- Mechanised applications.

The advantages of TIG are that it gives the best degree of control and good weld metal composition.

The disadvantages of TIG welding are its slow speed and that it is more expensive than other welding systems.

The conventional machine for MMA and TIG is the constant current drooping characteristic. This refers to the volt-amp output characteristics. By using drooping an alteration in arc length gives a very small change in current, but with the flat type power source an attempted alteration in arc length (volts) will have little effect. Hence arc length remains constant but a significant change in current will result.



METAL INERT GAS WELDING

With a 'flat' volts/amps characteristic an attempted alteration in arc length (volts) will have little effect, hence arc length (volts) remains constant but a significant change in current will result. This is often referred to as the 'self-adjusting arc'. Metal Inert Gas (MIG) welding is a 'flat' arc process (constant) voltage. Also known as Metal Active Gas (MAG); CO_2; Metal-arc Gas Shielded, flux core and GMAW (US). MIG can be used on all materials, in all positions, with high productivity and low heat input. There is no CO_2 MIG welding with stainless steel. Normally DC positive though some flux core uses DC negative.

Type of Operation.

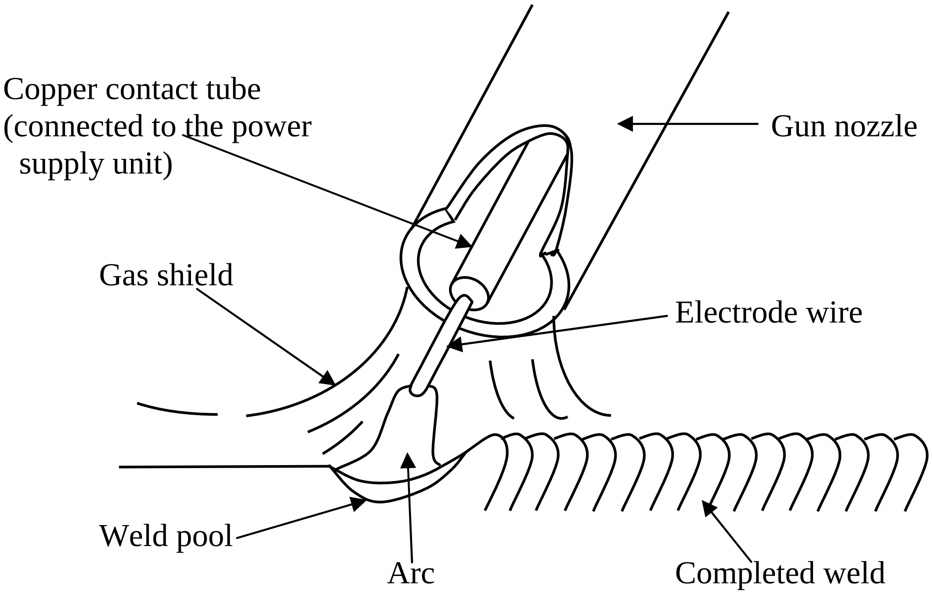
Manual, mechanised, semi-automatic and automated (robotics).

Mode of Operation.

An arc is maintained between the end of the bare wire electrode and the work piece. The wire is fed at a constant speed, selected to give the required current, and the arc length is controlled by the power source. The operator is not therefore concerned with controlling the arc length and can concentrate on depositing the weld metal in the correct manner. Hence the name 'semi-automatic' for manual operation, in which wire, gas and power are fed to a hand held gun via a flexible conduit.

The process can be operated at high currents (250 - 500 A) when metal transfer is in the form of a 'spray', but, except for aluminium, this technique is confined to welding in the flat and horizontal positions. For vertical and overhead welding special low current techniques must be used, i.e. 'dip' transfer or pulsed arc. The arc and weld pool are shielded by a stream of gas. The electrode can be solid or flux cored.

(In mechanised MIG and submerged arc welding the process may also be operated using constant current or drooping arc characteristics).



MIG/MAG Process Characteristics.

The heat source used to melt the parent metal is obtained from an electric arc that is formed between the end of a consumable electrode wire and the work piece. The arc melts the end of the electrode wire, which is transferred to the molten weld pool. The electrode wire is fed from a spool that is attached to the wire driving system and passes through a set of rolls, which are driven by a variable speed electric motor. By varying the speed of the motor, the level of the welding current can be adjusted - high wire feed speed gives high welding current. Altering the voltage can also vary the arc length - high voltages give longer arc lengths and vice versa.

In order to prevent the air reacting chemically with the molten metal, a shielding gas of either CO_2 or argon/CO_2 mixture is passed over the weld zone from a nozzle attached to the welding gun or torch. This protects the molten droplets passing across the arc and the molten weld pool.

Electrical power for the process is a direct current that is obtained from a transformer-rectifier. The welding gun or torch is connected to the positive pole of the power supply unit and electrical contact to the wire is obtained as close to the arc as possible by means of a copper contact tip or tube.

The metal at the end of the electrode is melted and transferred to the molten weld pool. The two main types of transfer are:

Spray or globular transfer.
Short-circuiting or dip transfer.

Spray Transfer/Globular Transfer.

This type of metal transfer generally occurs at high current and high arc voltage ranges, e.g., 250 - 600 Amps at 28 - 40 volts. As the current is increased the rate at which the droplets are transferred across the arc increases and they become smaller in volume. The droplets can be seen in a high-speed cine film but cannot be seen with the naked eye. It appears as if there is a spray of metal.

The type of shielding gas greatly affects the current rate at which the spray transfer occurs. The use of CO_2 as a shielding gas requires a much greater current density than argon to produce the same droplet rate.

With the use of high currents giving strong magnetic fields very directional arcs are produced. In argon shielding gases the action of these forces on the droplets is well balanced and transfer from wire to work is smooth with little or no spatter. However, with a CO_2 shield the forces tend to be out of balance giving rise to an arcing condition that is less smooth and spatter levels are heavier. Metal transfer under these conditions is normally called globular or free flight.

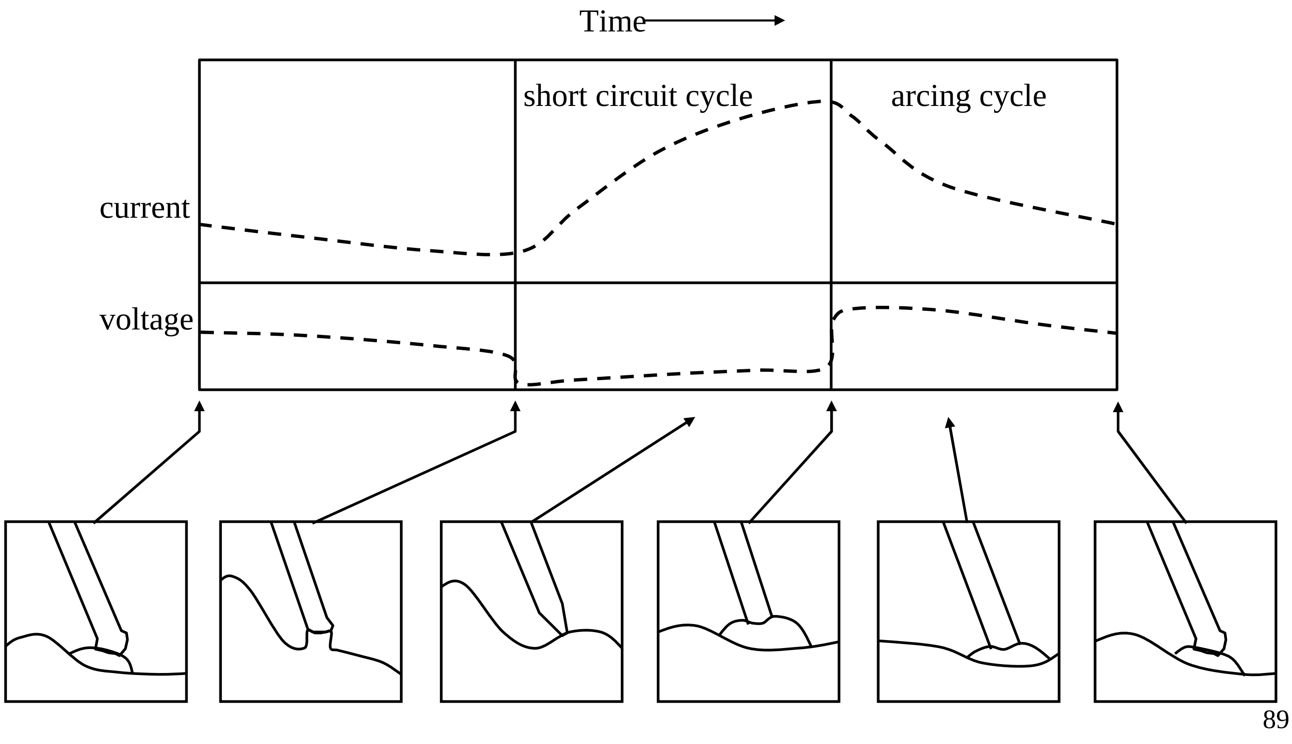
The welding conditions that give spray or globular transfer are normally associated with high deposition rates on medium and thick sections giving high productivity. It has a higher heat input and can only be used in the flat and HV positions except when welding aluminium when it can be used in all positions.

Short Circuiting Arc/Dip Transfer.

When using lower arc voltages and currents, generally in the 16 - 26 volt and 60 - 180 ampere ranges, metal transfer takes place during short circuits between the electrode and the weld pool, giving a lower heat input. These follow a consistent sequence of alternate arcing and short circuiting causing the end of the electrode wire to dip into the weld. As the wire touches the weld pool there is a rise of current, the resistance of the wire causes heating and the end of the electrode melts. The wire necks due to a magnetic pinch effect and the molten metal flows into the pool. During this short circuit period the current delivered by the power source is much higher than during arcing - typically 1000 - 1500 amps. This creates high forces that have an explosive effect on the weld pool and spatter is considerable. To reduce this effect an inductance is connected in series with the power supply and the arc to reduce the rate of rise of current during the short circuit period.

The short circuit is cleared more slowly and gently, and the spatter is reduced to an acceptable level. Ideally the droplets are transferred in an almost irregular dip/arc cycle taking place about 50 - 200 times a second. Too little inductance gives rise to unstable arcing conditions, excessive spatter and lack of fusion defects.

The dip transfer mode is used for the welding of thin sheet and medium plate, and for all thicknesses when welding in the vertical or overhead positions. (With thicker plate there can be lack of fusion problems.)



arc diminishing	short circuiting	necking	high current arc re-ignition	standing current arc	arc diminishing

The short circuit cycle.

Mixed Arc Transfer.

This is a globular transfer using medium volts and medium amperes. It is generally unusable having an unstable arc and high spatter levels. Use is mainly with flux cored wires in filling passes.

Pulsed Arc Transfer.

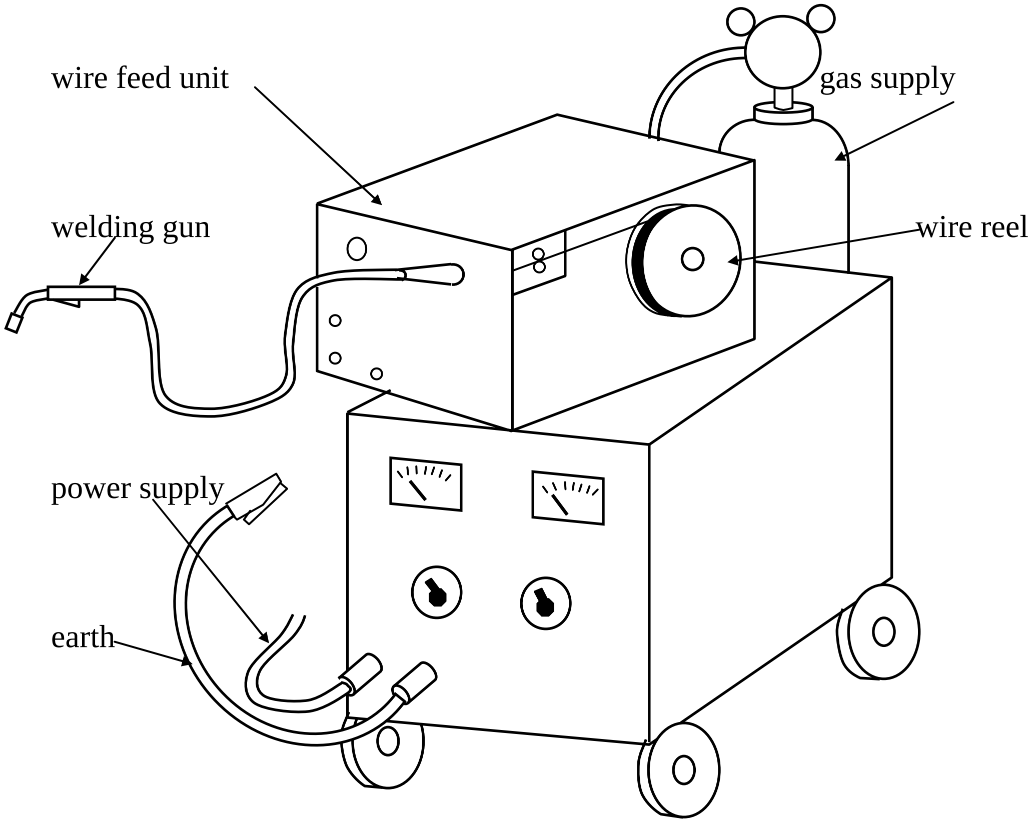
This is a synergic transfer of 50 - 250 kilohertz that combines short circuit and spray transfers. It uses high and low voltages and amperages, and can be used in all welding positions on plate thicknesses greater than 6 millimetres.

Welding Variables And Parameters.

1. Electrode extension - affects the amperage. Stick out length should be 10 - 15 mm.
2. Inductance - ' smoothes' the arc characteristic. Also called the choke. Set low gives excess penetration and high, no penetration.
3. Wire feed speed - amperage. Controls fusion and penetration.
4. Travel speed - controls depth of penetration.
5. Gas flow rate - protects weld from atmosphere.
6. Voltage - set on the welding machine and controls the arc length.
7. Tilt angle - back or fore hand should be not greater than 15° from the perpendicular.

The welding position and type of weld are further variables to be considered.

Welding Sets.



Sets are manufactured in a range of sizes, identified by current, similar to metal arc welding. Currents below 200 A can only give dip transfer operation, suitable for welding steel only.

Larger sets may have the wire reel and motor as a separate unit, so it can be placed near the job. Controls on the set adjust output voltage and may allow a choice of inductance. The wire speed control will be on the wire feed unit.

Electrical input is from single phase 240 V mains for small sets, or three phase 415 V for medium size and upwards. Output is always DC with a flat output characteristic for semi automatic and drooping output for mechanised.

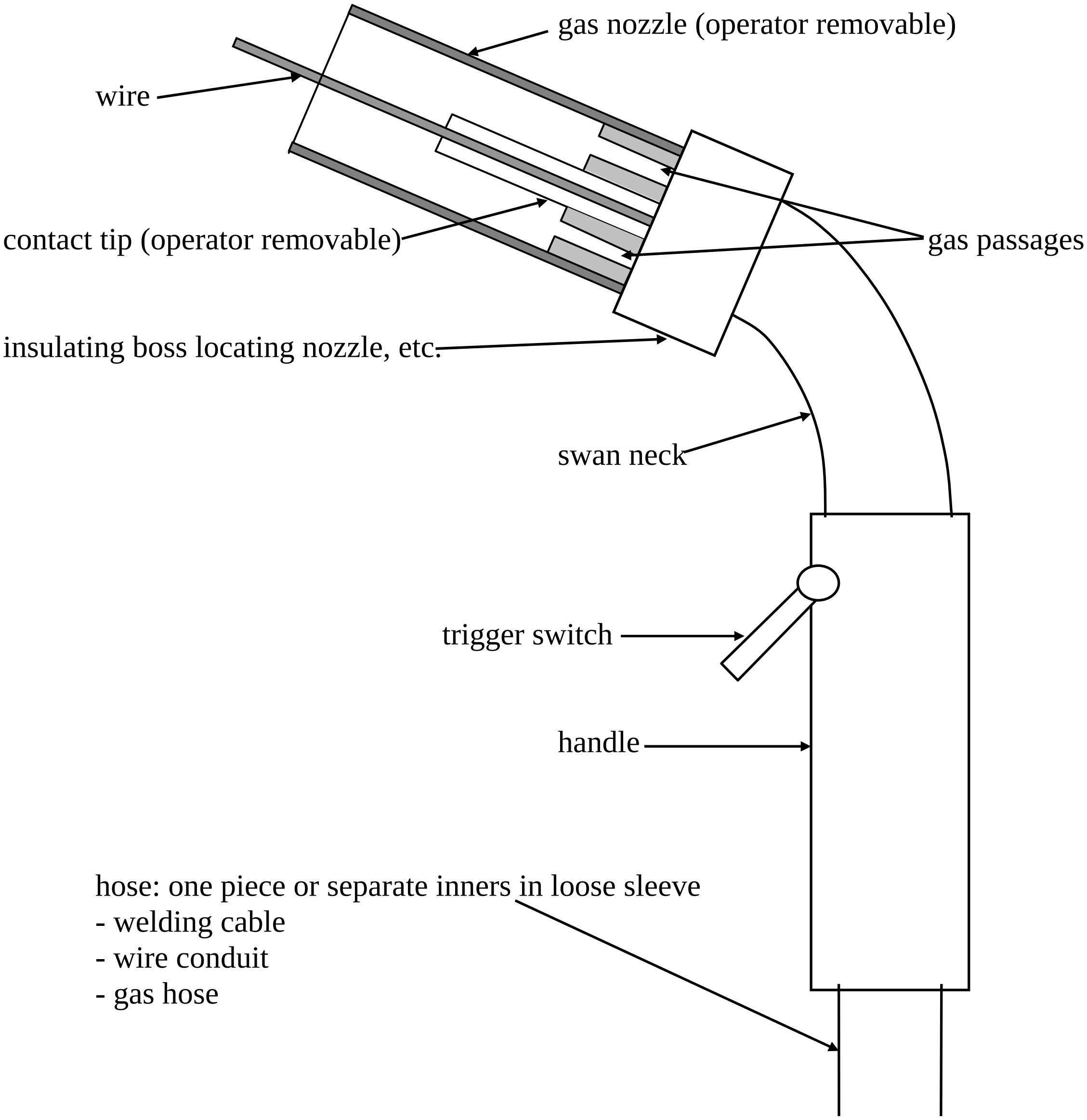
Sets which supply current in pulses (at 40 - 200 per second) give improved results on some jobs. Because the 'pulse-MIG' increases the number of controls, an electronic 'synergic' control system varies all the parameters in step to simplify adjustments.

Sets often have a built-in holder for a gas cylinder.

A set will usually be supplied with a suitable welding gun. Heavy duty guns may be water cooled and the set may have a water tank and cooling radiator built in.

When welding aluminium the wire is soft and tends to kink when pushed through a hose. A gun carrying a small reel of wire - 'reel-on-gun', obviates this.

MIG Welding Gun.



- trigger switch connection

Accessories.

Welding cables.
Connectors to set. } Similar to manual metal arc - one set usually included.
Clamps or clips.
Gun and connecting hose assembly to suit current, usually supplied with set.
Gas regulators and hose, connections to suit.
Vaporiser for carbon dioxide gas on industrial sets.
Cylinder stand.

Spares.

The following parts come into contact with the wire - spares are needed to replace worn parts, or if wire size or type is changed.

Inlet and outlet guides.
Drive rolls. } On drive assembly.
Contact tip in gun - needs fairly frequent replacement.
Gas shielding nozzle for gun - various sizes to suit different jobs.
Wire conduit liner - spring steel coil (like curtain wire) for steel electrode wire, or plastic tube for aluminium.

Typical Defects and Causes.

Lack of fusion.
Excessive penetration.
Silica inclusions (with steel only).
Solidification (centreline) cracking.
  a. Spray transfer current too high.
  b. Deep narrow prep.
Porosity.
  a. Gas flow too high or too low.
  b. Blocked nozzle.
  c. Leaking gas line.
  d. Draughty conditions.
  e. Nozzle to work distance too long.
  f. Painted, primed, wet or oily work surface.
  g. Damp or rusty wire.
Lack of penetration.
  a. Current too low.
  b. Prep to narrow.
  c. Root face too thick.
  d. Root gap too small.
  e. Worn tip causing irregular arcing.
  f. Irregular wire feed.
  g. Poor technique.
  h. Mismatched joint.

Undercut.

- a. Speed too high.
- b. Current too high.
- c. Irregular surface.
- d. Wrong torch angle.

Spatter.

- a. Inadequate choke.
- b. Voltage too low.
- c. Rusty or primed plate.

Crater cracking.

- a. Poor finishing technique.

Applications.

Structural steel.
Aluminium sections.
Stainless steel and nickel alloys.
Some offshore applications (flux core only).

SUBMERGED ARC WELDING

A flat arc process - (constant) voltage. It is used in beam, boom, tractor and multi-head type rigs.

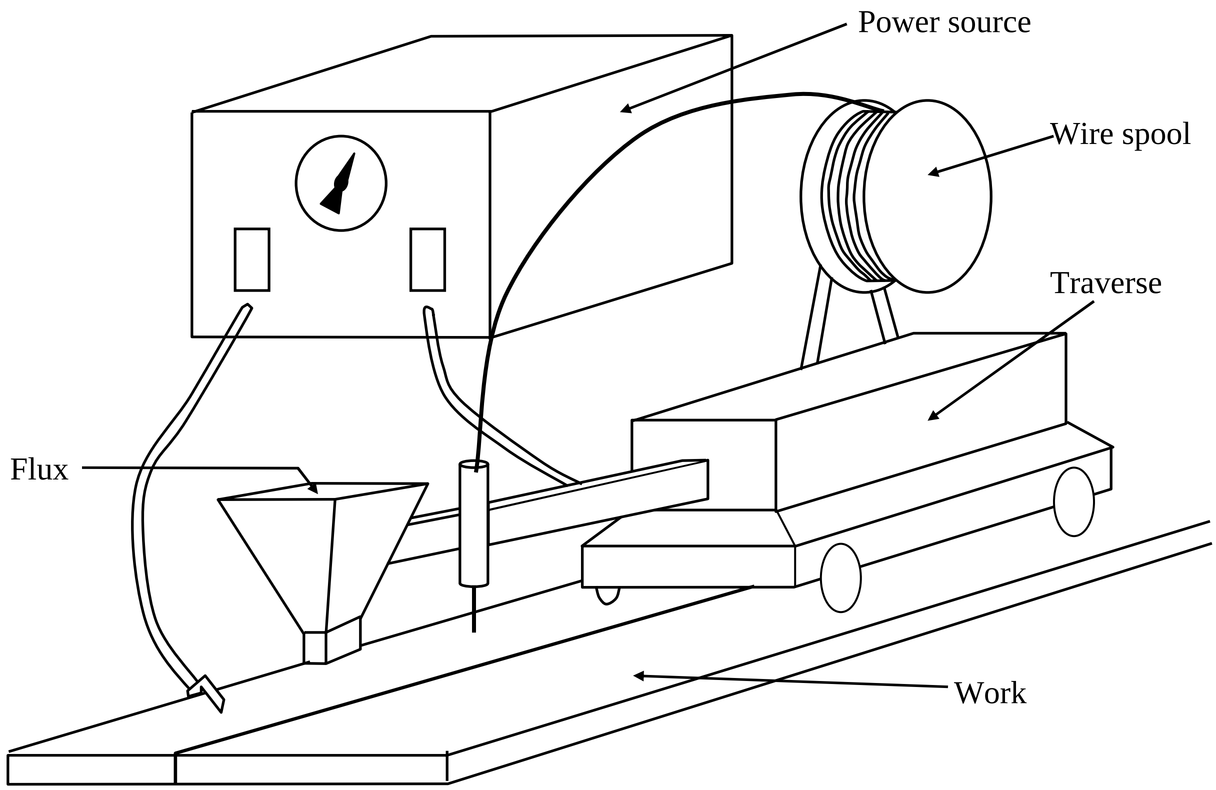
Type of Operation.

Mechanised, automatic or semi-automatic.

Mode of Operation.

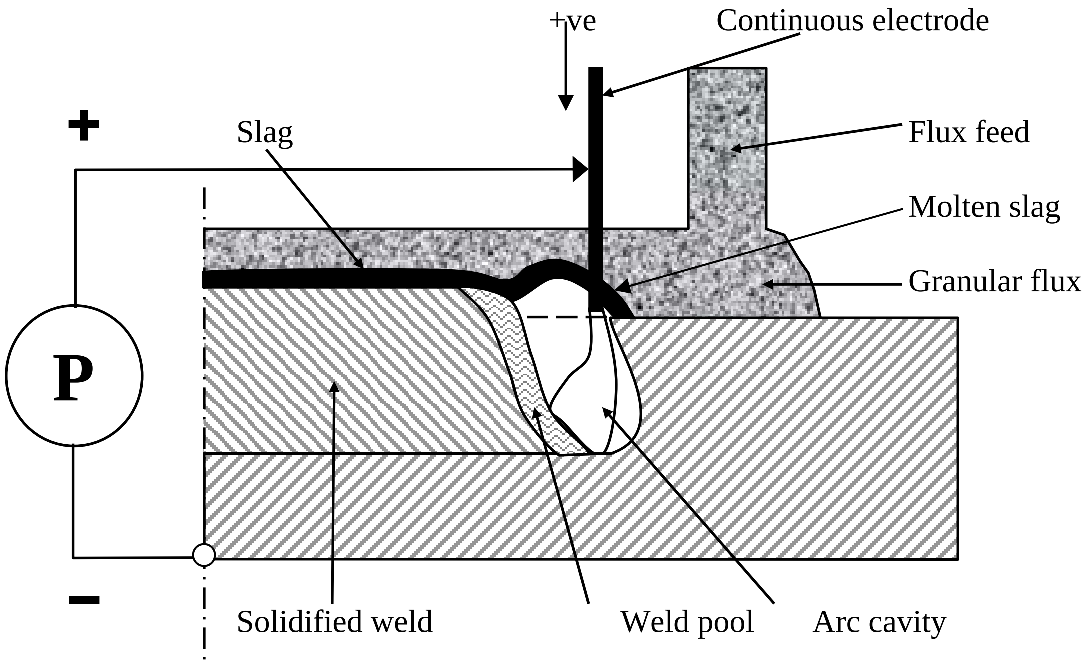
An arc is maintained between the end of a bare wire electrode and the work. As the electrode is melted, it is fed into the arc by a set of rolls, driven by a governed motor. Wire feed speed is automatically controlled to equal the rate at which the electrode is melted, thus arc length is constant (similar to MIG/MAG - constant voltage). The arc operates under a layer of granular flux, hence submerged arc. Some of the flux melts to provide a protective blanket over the weld pool. The remainder of the flux is unaffected and can be recovered and re-used, provided it is dry and not contaminated.

A semi-automatic version is available in which the operator has control of a welding gun that carries a small quantity of flux in a hopper.



Process And Equipment Fundamentals.

The principles of the submerged arc process are shown schematically below. A power source P, is connected across the contact nozzle on the welding head and the work piece. The power source can be a transformer for AC welding, or a rectifier (or motor generator) for DC welding. The filler materials are an uncoated continuous electrode and a granular welding flux fed down to the joint by way of a hose from the flux hopper. To prevent the electrode overheating at high currents the welding current is transferred at a point very close to the electric arc. The arc is burning in a cavity filled with gas (CO_2, CO, etc.) and metal fumes. In front, the cavity is walled in by unfused parent material, and behind the arc by solidifying weld metal. The covering over the cavity consists of molten slag. The diagram below also shows the solidified weld and the thin covering of solid slag, which has to be detached after the completion of each run.



Since the arc is completely submerged by the flux there is no irritating arc radiation that is characteristic of the open arc process - welding screens are therefore unnecessary.
The welding flux is never completely consumed so the surplus quantity left can be collected, either by hand or automatically, and returned to the flux hopper to be used again.
Although semi-automatic submerged arc welding equipment exists and is convenient for certain applications, most submerged arc welding uses fully mechanised welding equipment.
One of the main virtues of the submerged arc process is the ease with which it can be incorporated into fully mechanised welding systems to give high deposition rates and consistent weld quality. Weld metal recovery approaches 100% since losses through spatter are extremely small. Heat losses from the arc are also quite low due to the insulating effect of the flux bed and therefore the thermal efficiency of the process can be as high as 60%, compared with about 25% for MMA welding.
Flux consumption is approximately equal to the wire consumption, the actual ratio - weight of wire consumed: weight of flux consumed - being dependent on the flux type and the welding parameters used.
Welding parameters are maintained at their set values by the arc control unit. A feed back system is usually used to maintain a stable arc length so that a change in arc length (corresponding to a change in arc voltage) will produce an increase or decrease in the wire feed speed until the original arc length is regained.

Joint Preparation.

Joint preparation depends on plate thickness, type of joint e.g. circumferential or longitudinal and to some extent on the standards to which the structure is being made.
Plates of up to 14mm thick can be butt welded without preparation with a gap not exceeding 1mm or 10% of the plate thickness, whichever is the greater. Thicker plates need preparation if full penetration is to be obtained. Variable fit up cannot be tolerated.
A welder using stick electrodes can adjust his technique to cope with varying joint gaps and root faces or varying dimensions. Not so an automatic welding head. If conditions are set up for a root gap of 0.5mm and this increases to 2 or 3mm, burnthrough will occur unless an efficient backing strip is used. In such circumstances a hand welded root run using MIG or

MMA is advisable. All plate edges must be completely clean and free from rust, oil, millscale, paint, etc. If impurities are present and are melted into the weld, porosity and cracking can easily occur.

Time spent in minimising such defects by careful joint preparation and thorough inspection prior to welding is time well spent since cutting out weld defects and rewelding is expensive and time consuming.

Welding procedure.

In general the more severe the low temperature notch toughness requirements, the lower the maximum welding current that can be used. This is to minimise heat input and means that a multipass technique may be required. When welding stainless steels the heat input should be kept low because it has poor thermal conductivity and a high coefficient of expansion compared with mild steel. These two effects lead to overheating and excessive distortion if large diameter wires and high currents are used. Multi-run welds using small diameter wires are therefore recommended for stainless steels and high nickel alloys such as Inconel.

Welding Parameters.

Selection of the correct welding conditions for the plate thickness and joint preparation to be welded is very important if satisfactory joints free from defects such as cracking, porosity and undercut are to be obtained. The process variables, which have to be considered, are:

a. Electrode polarity.
b. Welding current.
c. Electrode diameter.
d. Arc voltage.
e. Welding speed.
f. Electrode extension.
g. Electrode angle.
h. Flux depth.

These are the variables that determine bead size, bead shape, depth of penetration and in some circumstances metallurgical effects such as incidence of cracking, porosity and weld metal composition.

a. Electrode polarity.

The deepest penetration is obtained with DC reverse polarity (DC electrode positive, DCEP) which also gives the best surface appearance, bead shape and resistance to porosity.

Direct current straight polarity (DC electrode negative, DCEN) gives faster burn off (about 35%) and shallower penetration since the maximum heat is developed at the tip of the electrode instead of at the surface of the plate. For this reason DC electrode negative polarity is often used when welding steels of limited weldability and when surfacing/cladding since, in both cases, penetration into the parent material must be kept as low as possible. The flux/wire consumption ratio is less with electrode negative polarity than with electrode positive polarity, so that alloying from the flux is reduced.

With DC polarity the maximum current used is 1000 amperes due to arc blow problems. In changing from positive to negative polarity some increase in arc voltage may be necessary to obtain a comparable bead shape.

Alternating current gives a result about half way between DC electrode positive and DC electrode negative and usually gives a flatter, wider bead. It can be used on multihead systems and is particularly useful when arc blow is a problem. It is often used in tandem arc systems where a DC positive electrode is used as the leading electrode and an AC electrode as the trail.

b. Welding current.

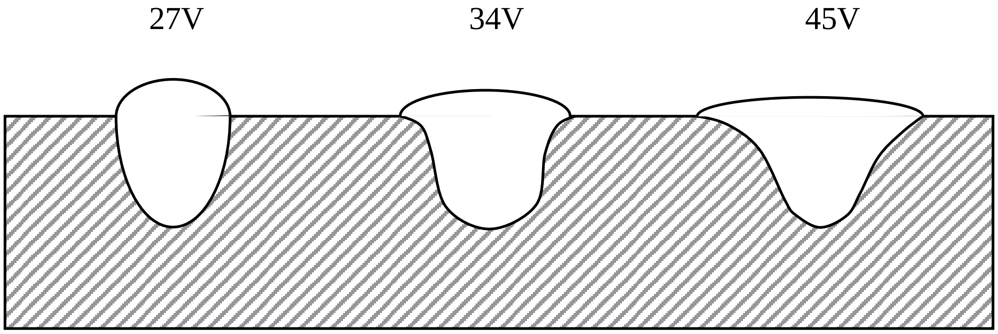
Increasing the wire feed speed increases the welding current so that the deposition rate increases as the welding current increases. The wire feed speed is the most influential control of fusion and penetration. The current density controls the depth of penetration - the higher the current density the greater the penetration. For a given flux, arc stability will be lost below a minimum threshold current density so that if the current for a given electrode diameter is too low arc stability is lost and a rugged, irregular bead is obtained. Too high a current density also leads to instability because the electrode overheats and undercutting may also occur.

c. Electrode Diameter.

For given current, changing the electrode diameter will change the current density. Therefore a larger diameter electrode will reduce penetration and the likelihood of burnthrough, but at the same time arc striking is more difficult and arc stability is reduced.

d. Arc voltage.

Arc voltage affects dilution rather than penetration. Bead on plate welds and square edged closed butt welds have increased width and dilution as the arc voltage increases, but depth of penetration remains the same. If the joint preparation is open, for example in a butt joint with a small angled 'V' preparation, increasing the arc voltage can decrease the penetration.



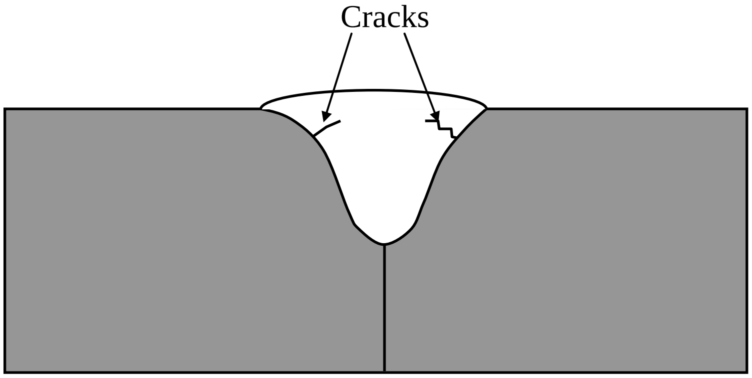
Effect of arc voltage on bead shape.

The arc voltage controls the arc length, flux consumption and weld metal properties. Increasing the arc voltage increases the arc length so that the weld bead width is increased, reinforcement is decreased, flux consumption is increased and the probability of arc blow is also increased. When alloying fluxes are used arc length, and hence arc voltage, is very important since at high arc voltages more flux is melted so that more alloying elements enter the weld metal. Thus arc voltage can affect weld metal composition.

e. Welding speed.

Welding speed or travel speed controls depth of penetration. Bead size is inversely proportional to travel speed. Faster speeds reduce penetration and bead width, increase the likelihood of porosity and, if taken to the extreme, produce undercutting and irregular beads. At high welding speeds the arc voltage should be kept fairly low otherwise arc blow is likely to occur.

If the welding speed is too slow burn through can occur. A combination of high arc voltage and slow welding speed can produce a mushroom shaped weld bead with solidification cracks at the bead sides.



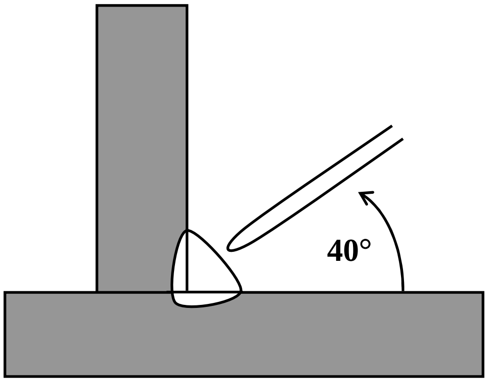
f. Electrode extension.

Also known as electrode stick out and alters the tip to work distance. Electrode extension governs the amount of resistance heating which occurs in the electrode. If the extension is short the heating effect is small and penetration is deep. Increasing the extension increases the temperature of the electrode, which decreases the penetration, but deposition rates are increased. Increased extension is therefore useful in cladding and surface applications, but steps have to be taken to guide the electrode, otherwise it wanders.

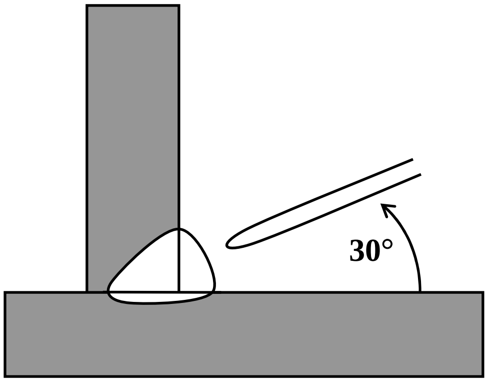
For normal welding the electrode extension should be 25 - 30mm for mild steel and less, about 20 - 25mm, for stainless steel. This is because the electrical sensitivity of stainless wire is appreciably greater than that of mild steel wire.

g. Electrode angle.

Since the angle between the electrode and the plate determines the point of application and direction of the arc force it has a profound effect on both penetration and undercut. The first figure shows the effect on horizontal/vertical fillet welds and the second figure compares the effect obtained with a vertical arc with those obtained with leading and trailing arcs. The effect on undercutting can be particularly marked.

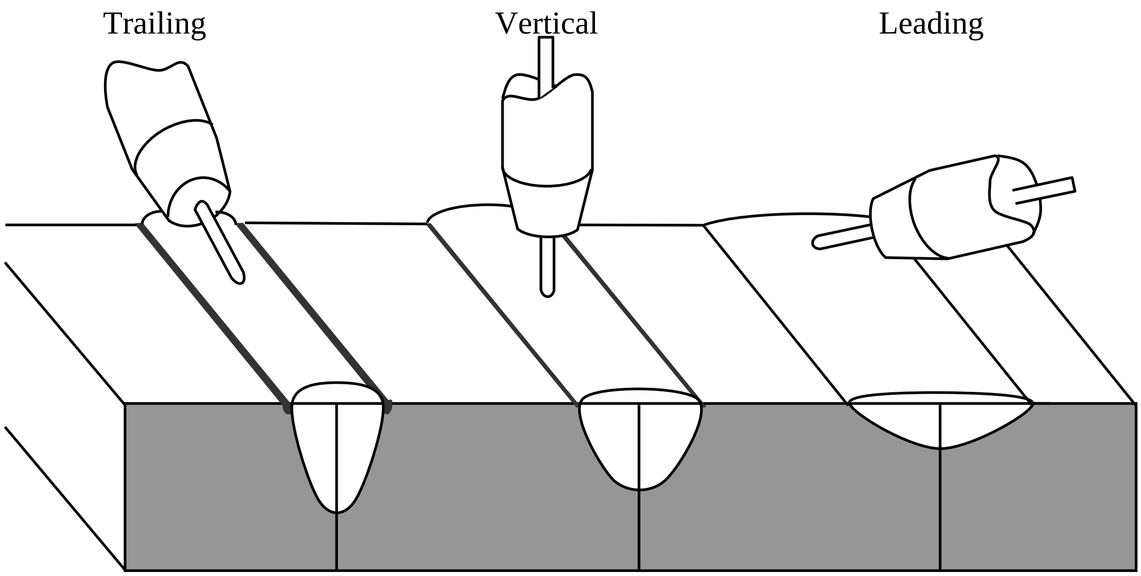


Equal leg length.



Deepest penetration.

Effect of electrode angle on HV fillet welds.



Penetration:	Deep	Moderate	Shallow
Reinforcement:	Maximum	Moderate	Minimum
Tendency to undercut:	Severe	Moderate	Minimum

Effect of electrode angle on butt welds.

h. Flux depth.

The depth of the flux, or flux burden, is often ignored and the powder heaped around the wire until the arc is completely covered. If optimum results are to be obtained the flux depth should be just sufficient to cover the arc, although the point where the electrode enters the flux bed light reflected from the arc should be just visible. Too shallow a flux bed gives flash-through and can cause porosity because of inadequate metallurgical protection of the molten metal. Too deep a flux bed gives a poor bead appearance and can lead to spillage on circumferential welds. On deep preparations in thick plate it is particularly important to avoid excessive flux depth otherwise the weld bead shape and slag removal can be unsatisfactory.

Fluxes.

Fluxes are graded by basicity index and in two types - agglomerated and fused. Particle size is important with larger currents requiring finer fluxes.

Fused fluxes are dark brown or black in colour with a glasslike surface and flakey in shape. They give a good surface profile and reasonable properties. Fused fluxes are general purpose fluxes that require no preheating.

Agglomerated fluxes are light in colour and roughly spherical in shape. They give the best mechanical properties and low hydrogen potential possible requiring the flux to be preheated (baked). Agglomerated fluxes absorb moisture so at the end of work they must be removed and dried.

Strip cladding.

Although most applications of the submerged arc process make use of single or multiwire systems using round wires, electrodes in the form of a strip are often used for cladding purposes. Strips are usually 0.5mm thick, the commonest strip width being 60mm, but wider strips e.g. 100mm can be used without any loss of quality. The big advantage of strip cladding is that penetration is low, particularly with DC electrode negative polarity, and deposition rate is relatively high. Modern fluxes designed for strip cladding have greater current tolerance than earlier types and use of currents up to 1200 amperes with austenitic stainless steel strips gives deposition rates of up to 22mg/hr with DC electrode positive polarity. Inconel can also be deposited and, provided the flux is low silica type and the Inconel strip used contains 2 - 3% Nb, good quality crack free deposits can be obtained. Monel, aluminium, bronze, nickel and 13% Cr strips have also been successfully used as strip cladding electrodes. Good electrical contact between the strip and feed nozzle is essential.

Typical Defects And Causes.

Lack of penetration.

a. Electrode too large for weld prep.
b. Current too low.
c. Root face too large.
d. Root gap too small.
e. Mismatch.
f. Wrong polarity.
g. Stick out length too long.
h. Insufficient cleaning of second side in double sided preps.

Porosity.

a. Dirt in weld prep.
b. Dirt/rust on electrode.
c. Damp or contaminated flux.
d. Incorrect current type for flux.
e. Insufficient flux covering.
f. Material defects. (laminations, inclusions, high sulphur)

Centreline cracking.

a. Current too high.
b. Weld prep too narrow.
c. Material with high sulphur or phosphorus content.

Slag inclusions.

a. Inadequate inter run cleaning.
b. Poor joint configuration.
c. Poor positioning of weld runs.
d. Voltage too low.

Spatter.

a. Current too high.
b. Incorrect current type for flux.

Also lack of fusion, undercut, excessive penetration and weld profile defects.

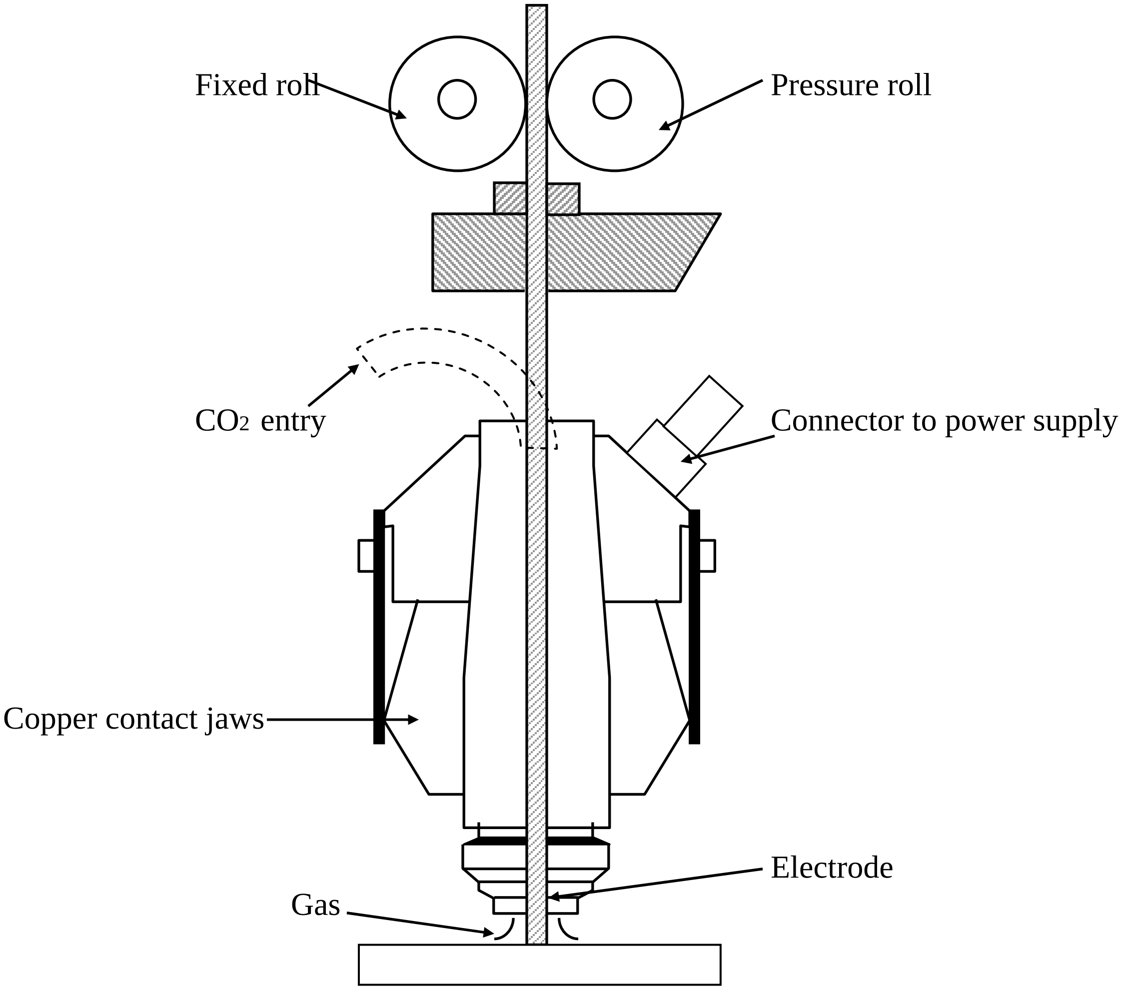
Applications.

Ship building.
Heavy fabrication.
Circumferential welds (e.g. rotated vessels).

Longitudinal seams (e.g. for pipelines).
Cladding applications.

AUTOMATIC METAL ARC

A fusion welding process also known as Fusarc welding.



Automatic metal arc head with CO_2 shield.

Type of Operation.

Mechanised or automatic.

Mode of Operation.

An arc is maintained between a fluxed electrode and the work. The arc length is controlled by a variable speed motor and feed roll system. The arc may have an additional CO_2 gas shield. The weld is protected and controlled by the flux coating as in MMA.

Operating Parameters.

Current range:	200 - 1000 Amps.
Deposition rate:	1 - 15 kg/hr.
Range of thickness:	6mm and upwards.
Types of joint:	butt and fillet.

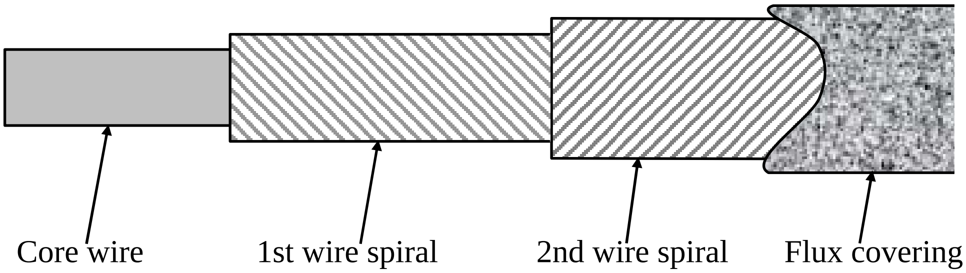
Welding positions: butt joints - flat, fillet welds - flat and HV.
Access and portability: good.

Equipment.

Welding head.
Control panel.
Electrode feed unit. - May have additional CO_2 for shielding.
Power source. - Transformer, rectifier or generator. (AC/DC up to 1000 amps.)
Work moving equipment. (And/or head moving equipment.)

Consumables.

Wire wound, flux coated electrode 2.75 - 7.5mm on wire diameter. Supplied in coils of 13.5 - 22.5 kg in weight. The electrode composition can be selected to suit the parent metal. CO_2 gas in some cases.



Construction of electrode for automatic metal arc welding.

Materials.

Only carbon, low alloy high tensile and stainless steels.

Typical applications.

Medium scale fabrication. Pipework. Shipbuilding. Chemical plant.

Overall advantages.

Good deposition rate. Good quality weld metal. Tolerant to poor fit up and open air work.

Overall limitations.

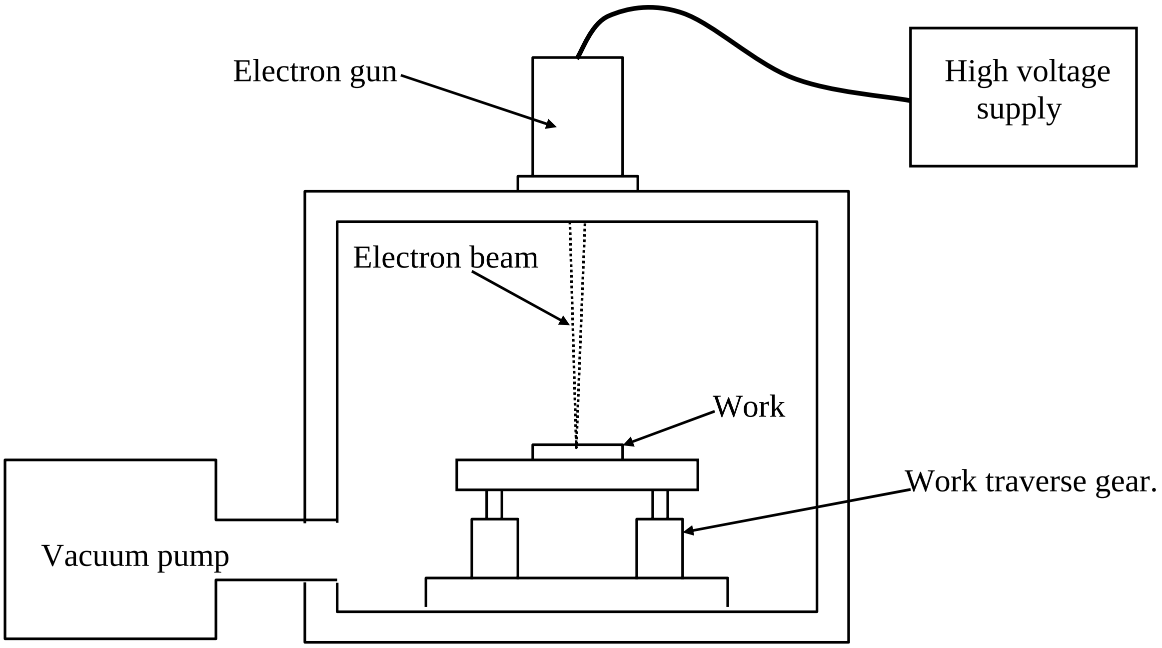
Open arc. Electrode needs careful handling. Limited penetration.

Safety.

Intense arc. Copious fumes.

ELECTRON BEAM WELDING

A fusion welding process.



Type of Operation.

Automatic or mechanised.

Mode of Operation.

The work piece is heated by the bombardment of a beam of electrons produced by an electron gun.
Filler material may be added if necessary.
Though the work is normally carried out within a vacuum chamber, electron guns are currently under development which allow a beam to travel a short distance through air.

Operating Parameters.

Current range:	10 - 500 mA.
Voltage range:	10 - 150 kV.
Range of thickness:	0.2mm - 100mm.
Type of joint:	mostly butt.
Welding position:	limited by equipment.
Access:	good - but work normally must be lifted into and out of a fixed chamber.
Portability:	poor.

Equipment.

High voltage power supply.

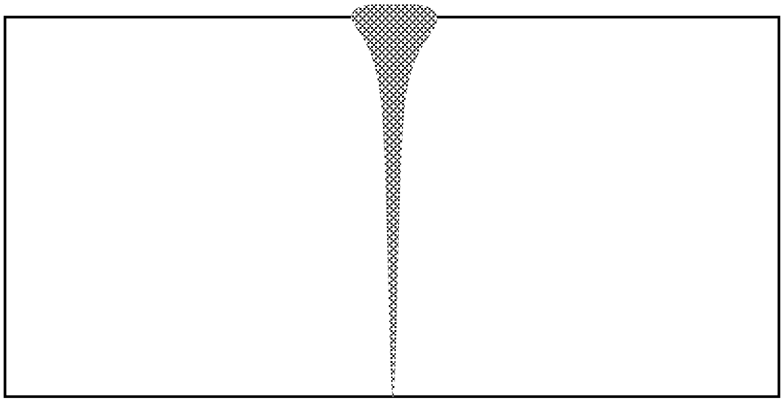
Electron gun.
Vacuum chamber.
Vacuum pump.
Traversing unit - for work or electron gun.

Consumables.

Filler wire may be added if necessary.

Materials.

Any metal compatible with a vacuum when molten.



Cross section of typical electron beam weld.

Overall advantages.

Excellent penetration.
Low distortion.
No weld metal contamination.
High welding speeds.
Ability to weld many normally non weldable materials.

Overall Limitations.

High equipment cost.
Vacuum necessary.
Extreme accuracy needed in work preparation.

Typical Applications.

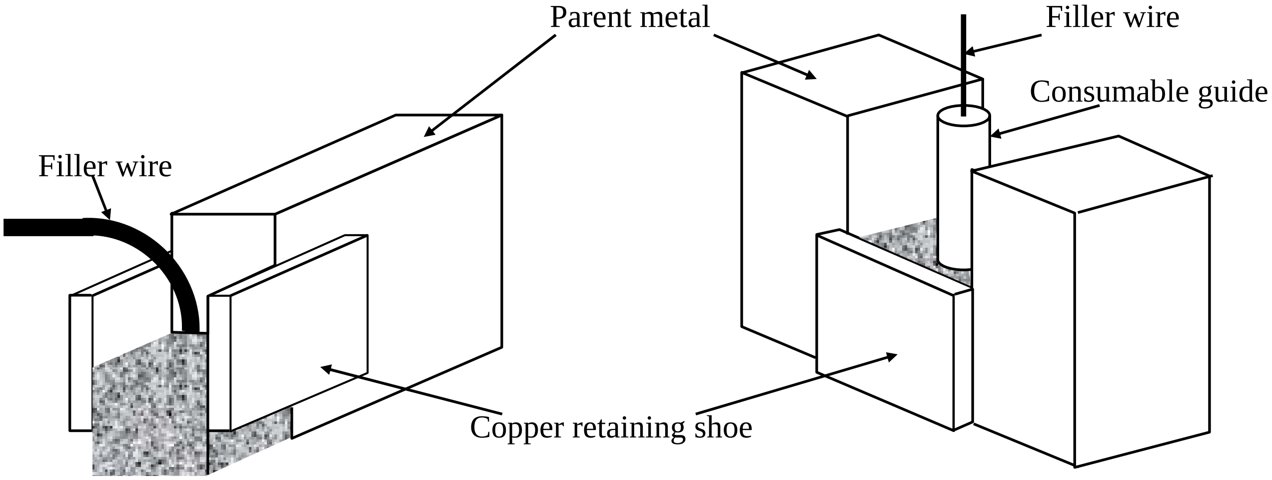
Gear clusters/shaft joints.
Turbine blade root joints.
Fully machined components - low distortion.
Difficult to weld materials.

Safety.

X-radiation emitted. (Normally absorbed by chamber walls.)
High voltage.
Operators can be trapped in large chambers.

ELECTRO-SLAG WELDING

A fusion welding process with two systems - electro-slag and consumable wire guide/nozzle.



Electro-slag. *Consumable guide.*

Type of Operation.

Mechanised.

Mode of Operation.

Welding is carried out vertically. The plates to be welded are set up with a 25 - 50mm gap (depending on thickness) between their edges (unprepared) and the electrode is introduced into the gap pointing vertically down. An arc is struck and granular flux added which is melted by the arc. The molten flux extinguishes the arc and the heat required for welding is then produced by the passage of current through the electrically resistive flux. Water cooled copper 'shoes' are clamped against the plate surfaces, covering the gap on each side, to retain the molten flux and also the weld pool formed by the melting of the electrode and parent plate.

In electro-slag welding the electrode feed unit is moved up the joint as the gap is progressively filled with molten weld metal, and the retaining shoes are also moved up at the same speed.

The electrode in consumable guide welding is fed through a long tube which is positioned in the joint gap. As welding progresses the electrode wire and the guide are melted into the weld pool. The system is mechanically more simple since no vertical up movement of the wire feed unit is required.

Operating parameters.

Current range: 450 - 1500A per wire AC or DC.
Welding speed: 0.3 - 3m per hour.
Range of thickness: 20mm upwards.
Welding position: vertical.
Types of joint: butt and T-joints.

Access: poor.
Portability: fair.

Equipment.

Power source.
Wire feed unit.
Vertical traverse (for electro-slag only).
Water cooled copper shoes.

Consumables.

Electrode wires are similar to those used for submerged arc welding, and supplied on standard spools weighing 25 - 75 kg. Consumable guides may be in the form of tubes or specially made hollow sections according to the particular application. The composition of both wires and guides must be chosen to suit the parent material and with reference to required weld metal properties. Fluxes are specially formulated and resemble submerged arc welding fluxes.

Materials.

Steels.

Typical Applications.

Thick pressure vessels.
Thick civil engineering fabrication.
Shipbuilding.

Overall Advantages.

Fast completion of joints in thick plate.

Overall Limitations.

Only for vertical or near vertical joints.
Welds have poor impact properties unless heat treated.

Safety.

Molten metal spillage must be considered.

MULTICHOICE PAPER ONE

1. When ‘hydrogen control’ is specified for a manual metal arc welding project the electrode would normally be:
   a. Cellulose
   b. Iron oxide
   c. Acid
   d. Basic

2. You would certainly recognise a hydrogen controlled flux covered electrode from its:
   a. Colour
   b. Length
   c. Trade name
   d. BS639/AWS code letter

3. When manual metal arc welding is being carried out on an open construction site, which group of welders are most likely to require continuous monitoring?
   a. Concrete shuttering welding teams
   b. Pipe welding teams
   c. Plate welders
   d. Plant maintenance welders

4. You notice manual metal arc electrodes, stripped of flux, are being used as filler wire for TIG welding. You would object because:
   a. It is too expensive
   b. The wire would be too thick
   c. The metal composition may be wrong
   d. The wire is too short

5. When open site working, serious porosity in metal arc welds is brought to your attention. What would you investigate?
   a. Electrode type
   b. Power plant type
   c. Electrode storage
   d. Day temperature

6. The steel composition in a structural contract is changed from 0.15% carbon 0.6% manganese, to 0.2% carbon 1.2% manganese. This might influence the incidence of:
   a. Porosity
   b. Cracking in the weld area
   c. Undercut for fillet welds
   d. Lack of fusion defects

7. One of the following alloys is non-magnetic - which?
   - a. 4.0% chromium molybdenum
   - b. 12.0% chromium
   - c. Austenitic stainless steel
   - d. 9.0% nickel steel

8. When TIG welding austenitic stainless steel pipe, argon gas backing is called for. This is to:
   - a. Prevent oxidation
   - b. Prevent underbead cracking
   - c. Prevent porosity
   - d. Control the penetration bead shape

9. Pre-heating a carbon steel manual metal arc welding is carried out to minimise the risk of:
   - a. Scattered porosity
   - b. Worm hole porosity
   - c. Parent metal cracking
   - d. Lack of penetration

10. In UK practice, BS499 specifies that the drawing dimension quoted for a fillet weld is the:
   - a. Leg length
   - b. Throat thickness
   - c. Weld width
   - d. Actual throat thickness

11. For open site manual metal welding the following equipment is available. Which would you choose for safe site working?
   - a. Single operator transformer
   - b. Multi operator transformers
   - c. AC/DC composite power unit
   - d. Diesel engine driven motor generator

12. If submerged arc welding is used to make butt welds, which would you be most critical of?
   - a. The root gap tolerance
   - b. The angle of preparation
   - c. The root face width
   - d. The gas cut finish

13. During CO2 welding, the arc length is most likely to be affected by:
   - a. The wire diameter
   - b. The current return connections
   - c. The gas flow rate
   - d. The torch to work angle

14. Preheating for arc welding applies to:
   - a. Assembly welding only
   - b. Assembly and tack welding
   - c. Joints over 25 mm thick only
   - d. Cruciform welds only

15. Which one of the following statements is correct?
    - a. Preheating increases hardness
    - b. Preheating increases cooling
    - c. Preheating increases dilution
    - d. Preheating increases shrinkage stress

16. You see a welder using an oxy-acetylene flame with a long feathered inner cone. What would be the effect of this on carbon steel?
    - a. The weld would be hard and brittle
    - b. The weld could be too soft
    - c. There will be no effect on the weld
    - d. The weld will have undercut

17. A welder qualification test is to verify:
    - a. The skill of the welder
    - b. The quality of the materials
    - c. The non-destructive test procedures
    - d. The manufacturing methods

18. A fabricating procedure calls for fillet welds to be 'blended in' by grinding. This influences:
    - a. HAZ. cracking
    - b. Fatigue life
    - c. Residual stress
    - d. Yield strength

19. Bend test specimens have been taken from a 25 mm thick carbon steel butt weld. Which would show lack of inter-run fusion?
    - a. Side bend
    - b. Root bend
    - c. Face bend
    - d. Guided bend

20. Lamellar tearing has occurred in a steel fabrication. BEFORE welding could it have been found by:
    - a. X-ray examination
    - b. Dye penetrant
    - c. Ultrasonic examination
    - d. It would not have been found by any inspection method

21. You are to oversee the arc welding of some machine fittings and find that they are cadmium plated. Would you:
    - a. Permit it to proceed
    - b. Permit it to proceed with fume extraction
    - c. Stop the operation at once
    - d. Advise the welder to drink milk and proceed

22. One of the reasons for excluding hydrogen from the weld metal is to prevent the weld from:
    - a. Cracking
    - b. Cooling slowly
    - c. Cooling quickly

d. Expanding

23. When a metal regains its original shape when a stress acting upon it is removed, the metal is said to have:
    a. Ductility
    b. Plasticity
    c. Malleability
    d. Elasticity

24. Proof stress is used when non-ferrous metals are undergoing tensile tests to determine the equivalent:
    a. Tenacity
    b. Elasticity
    c. Yield strength
    d. Tensile strength

25. To test a component for vibrational loading, a suitable mechanical test would be:
    a. Impact
    b. Tensile
    c. Compressive
    d. Fatigue

26. The main reason for pre-heating medium and high carbon steels before cutting by oxy-fuel gas technique is to:
    a. Improve the quality of the cut
    b. Increase the cutting speed
    c. Refine the grain structure
    d. Prevent hardening and cracking

27. One purpose of a microscopic examination of a weld is to establish the:
    a. Strength of the weld
    b. Number of alloying elements
    c. Grain size
    d. Number of runs used

28. The predominant structure of an hyper-eutectoid steel that has been quenched at above its upper critical point will be:
    a. Austenite
    b. Martensite
    c. Troostite
    d. Sorbite

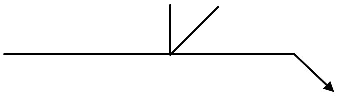
29. When weld metal refinement takes place in a multi-run deposit, it is known by the term:
    a. Weld annealing
    b. Weld refining
    c. Weld normalising
    d. Weld recrystallisation

30. One advantage of metal gas arc shielded welding is:
    - a. Can be used in draughty locations without protection
    - b. Produces a deposit low in hydrogen content
    - c. Any welding position can be welded with spray transfer
    - d. Fine spatter at nozzle restricting gas flow

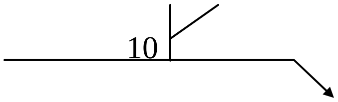
MULTICHOICE PAPER TWO

1. BS499 communicates by the use of symbols the type of joint preparation to be used. Which of the following symbols indicates the depth of weld penetration required on the joint?

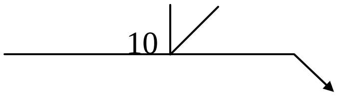
a.



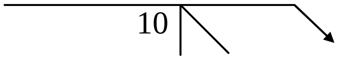
b.



c.

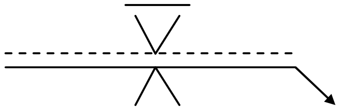


d.

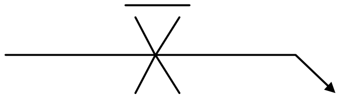


2. Which of the following symbols would indicate that a weld has to be finished on the 'other' side of the weld?

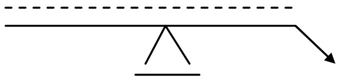
a.



b.



c.



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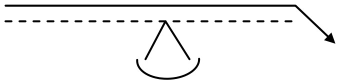

3. The use of flux with gas shielded metal arc welding allows:
    - a. Sheet metal to be welded
    - b. A stable arc when using high current densities
    - c. Aluminium to be welded
    - d. Less dilution of the weld by the parent metal

4. In MMA welding what parameter is used for control of penetration into the base material?
    - a. Voltage
    - b. Welding speed
    - c. Iron powders in the coating
    - d. Current

5. In the welding of a butt joint from one side, the profile of the root bead is controlled by:
    a. Root face
    b. Bevel angle
    c. Root gap
    d. All of the above

6. What type of power characteristic is required for manual welding?
    a. Constant voltage
    b. Flat characteristic
    c. Drooping characteristic
    d. DC generator

7. Which of the following tests would indicate the toughness of weld metal/parent metal - HAZ?
    a. Macro
    b. Nick break
    c. Hardness
    d. Charpy vee notch

8. Degreasing components is essential for quality welding but some agents may:
    a. Cause corrosion problems
    b. Give off phosgene gas
    c. Leave residues
    d. All the above

9. Which of the following elements has the greater effect on the hardenability of a steel plate?
    a. Molybdenum
    b. Chromium
    c. Titanium
    d. Carbon

10. In MAG/CO2 welding which parameter gives the greatest control of weld appearance during dip transfer or short-circuiting welding?
    a. Wire stick-out length
    b. Amperage
    c. Wire feed speed
    d. Inductance

11. In MMA welding, the slags produced can be varied to suit the welding position. Which type of slag would be required for welding in the HV position?
    a. Fluid
    b. Viscous
    c. Semi fluid
    d. None of the above

12. The weld metal deposit of MMA electrodes achieves its mechanical strength through:
    a. The core wire
    b. The flux coating
    c. Iron powders with the flux coating
    d. None of the above

13. What constituent is needed in the coating of an electrode to prevent the formation of porosity in the welding of a rimming steel?
    a. Iron powders
    b. Calcium fluoride
    c. Silicon
    d. Calcium carbonate

14. Welds made with high heat inputs show a reduction in which of the following properties?
    a. Ductility
    b. Toughness
    c. Fatigue strength
    d. Mechanical strength

15. In the welding of austenitic pipework the bore is usually purged with argon to:
    a. Prevent formation of porosity in the weld
    b. Prevent burn-through in the root run
    c. Prevent oxidation of the root bead
    d. Eliminate the formation of hydrogen

16. In X-ray work the quality of the radiographic image is assessed by the:
    a. Density of the film
    b. IQI indicator
    c. KVA available
    d. Stand-off distance

17. A steel described as QT will have improved tensile properties because it has:
    a. Had control of chemical composition
    b. Been heat-treated
    c. Been quality tested
    d. Been vacuum melted

18. Which one of the following types of steel would give rise to the formation of porosity when autogenously welded with an arc process?
    a. Fully killed steel
    b. Semi killed steel
    c. Rimming steel
    d. Fine grained steel

19. In submerged arc welding the use of excessively high voltage would result in:
    a. Insufficient flux melting
    b. Excessive flux melting
    c. Slag removal difficulties

d. Spatter

20. Cellulosic electrodes are often used when welding the root pass of pipes in the field because:
    a. Hydrogen control is needed
    b. There are iron powders in the electrode
    c. Higher arc voltage can be obtained
    d. Shorter arc length can be obtained

21. In the welding of austenitic stainless steels, the electrode and plate material can be purchased with low carbon contents. The reason for this is to prevent:
    a. Cracking in the heat affected zone
    b. The formation of chromium carbides
    c. Cracking in the weld metal
    d. Distortion

22. Submerged arc fluxes can be supplied in two forms. These are:
    a. Sintered and agitated
    b. Agitated and fused
    c. Sintered and agglomerated
    d. Fused and agglomerated

23. In a steel that has improved creep properties at elevated temperatures, which one of the following elements helps in this improvement?
    a. Tungsten
    b. Manganese
    c. Molybdenum
    d. Carbon

24. Welding a steel plate with a CE of 0.45 would require preheating to:
    a. Prevent the formation of sulphides
    b. Prevent hardening in the HAZ
    c. Prevent the formation of carbides
    d. To improve mechanical properties in the weld

25. Which of the following processes uses the 'keyholing' system of fusion?
    a. Friction welding
    b. Diffusion bonding
    c. Electron beam welding
    d. Autogenous TIG welding

26. In friction welding the metal at the interface is in the:
    a. Liquid state
    b. Solid state
    c. Plastic state
    d. Elastic state

27. Welding procedures may require welds to be deposited at a controlled rate of heat input. High heat inputs would:
    - a. Have poor profile
    - b. Have larger grain size
    - c. Have high hardness in the HAZ
    - d. Have low elongation properties

28. In a tensile test a brittle material would be indicated if the fracture surface:
    - a. Shows a reduction in size
    - b. Is flat and featureless
    - c. Breaks in the parent material
    - d. Breaks at 45° to the load

29. What destructive test would be required to ascertain the likelihood of cracking in the heat affected zone of a weld?
    - a. Nick break
    - b. Side bend test
    - c. Charpy impact test
    - d. Macro test

30. In submerged arc welding excessive arc voltage may cause:
    - a. Excessive penetration
    - b. Change in weld metal composition
    - c. Narrow weld width
    - d. Excessive bead profile

MULTICHOICE PAPER THREE

1. The British code for visual inspection requirements is:
    - a. BS 4872
    - b. BS 499
    - c. BS 4870
    - d. None of the above

2. A code of practice for visual inspection should include the following:
    - a. Before, during and after welding activities
    - b. Before welding activities only
    - c. After welding activities only
    - d. None of the above

3. Incomplete root penetration in a butt joint could be caused by:
   - a. Excessive root face width
   - b. Excessive root gap size
   - c. Low current setting
   - d. Both A and C

4. Incomplete root fusion would certainly be caused by:
   - a. Linear misalignment
   - b. Incorrect tilt angle
   - c. Differing root face widths
   - d. All of the above

5. When visually inspecting a completed single vee butt weld cap, you would certainly assess:
   - a. Cap height
   - b. Toe blend
   - c. Weld width
   - d. All the above

6. You notice a very 'veed' ripple shape. This is most likely caused by:
   - a. Poor consumable choice
   - b. Welding position
   - c. Excessive travel speed
   - d. All the above

7. Toe blending is important as it may affect:
   - a. Corrosion
   - b. Fatigue life
   - c. Overlap type defects
   - d. All the above

8. Slag inclusions would occur with:
   - a. Manual metal arc
   - b. Metal inert gas
   - c. Submerged arc welding
   - d. Both A and C

9. Undercut is principally caused by:
   - a. Excessive amps
   - b. Excessive volts
   - c. Excessive travel speed
   - d. All the above

10. Undercut is normally assessed by:
    - a. Its depth
    - b. Its length

c. It's blending
d. All the above

11. A welding procedure is useful to:
a. Give information to the welder
b. Give information to the inspector
c. Give confidence to a product
d. All the above

12. An essential variable may:
a. Change the properties of a weld
b. Influence the visual acceptability
c. Require re-approval of a weld procedure
d. All the above

13. A magnifying glass may be used during visual inspection, but BS 5289 states that its magnification should be:
a. Up to 5 ∅
b. 2 to 2.5 ∅
c. 5 to 10 ∅
d. None of the above

14. When visually inspecting a fillet weld it would normally be sized by:
a. The leg lengths
b. The actual throat thickness
c. The design throat thickness
d. Both A and C

15. A planar defect is:
a. Incomplete fusion defects
b. Slag inclusion
c. Incomplete penetration
d. Both A and C

16. Penetrant inspection and magnetic particle inspection are mainly used:
a. To aid visual inspection
b. Because the application says so
c. To confirm visual uncertainties
d. All the above

17. Defects outside the limits specified in a standard should always be:
a. Repaired
b. Reported to 'a senior person'
c. Assessed along with other defects
d. All the above

18. MIG welding tends to be susceptible to lack of fusion problems. This is because of:
a. Poor maintenance of equipment
b. Incorrect settings

c. Poor inter-run cleaning
d. All the above

19. MMA electrodes can be grouped into three <u>main</u> types. These are:
    a. Basic, cellulosic and rutile
    b. Neutral, cellulosic and rutile
    c. Basic, cellulosic and neutral
    d. None of the above

20. The main cause of porosity in welded joints is:
    a. Poor access
    b. Loss of gas shield
    c. 'Dirty' materials
    d. All the above

21. Cracks in welds may be due to:
    a. Solidification problems
    b. Hydrogen problems
    c. Excessive stresses
    d. All the above

22. A weave technique may give rise to:
    a. Better profiles
    b. Improved toe blending
    c. Improved ripple shape
    d. All the above

23. With reference to a root penetration bead you would certainly assess:
    a. Root fusion and penetration
    b. Root concavity
    c. Burnthrough
    d. All the above

24. In a fatigue failure the appearance of the fracture surface is characteristic. It would be:
    a. Rough and torn
    b. 'Chevron'-like
    c. Smooth
    d. None of the above

25. Stray arcing may be regarded as a serious defect because:
    a. It may reduce the thickness dimension of a component
    b. It may cause loquation cracks
    c. It may cause hard zones
    d. All the above

26. Overlap in welds could be influenced by:
    a. Poor welding technique
    b. Welding process

- c. Welding position
- d. All the above

27. Flame cut preparations may, during welding, increase the likelihood of:
    - a. Cracking
    - b. Misalignment problems
    - c. Inclusions
    - d. All the above

28. Macroscopic examination requires any specimen to be inspected:
    - a. Once, after etching
    - b. Twice, before and after etching
    - c. Using a microscope
    - d. None of the above

29. Which of the following may be classed as a more serious defect:
    - a. Slag inclusions
    - b. Fusion defects (inter-run)
    - c. Fusion defects (surface)
    - d. Porosity

30. A code of practice is:
    - a. A standard for workmanship only
    - b. A set of rules for manufacturing a specific product
    - c. Levels of acceptability of a weldment
    - d. None of the above

MULTICHOICE PAPER FOUR

1. Movement of the arc in MMA welding by magnetic forces is called:
    - a. Arc deviation
    - b. Arc misalignment
    - c. Arc blow
    - d. Arc eye

2. A metallurgical problem most associated with submerged arc welding is:
    - a. Hydrogen cracking in the HAZ
    - b. Solidification cracking in the weld metal
    - c. Hydrogen cracking in the weld metal
    - d. Lamellar tearing in the weld metal

3. Oxy pressure and nozzle size in flame cutting would influence:
    a. The temperature required for cut initiation
    b. The ability to cut stainless steels
    c. The depth of the cut obtainable
    d. None of the above

4. The main usage of arc cutting/gouging processes is:
    a. The cutting of single bevel preparations
    b. The removal of deposited welds
    c. The cutting of single U type preparations
    d. The cutting/gouging of non-ferrous materials only

5. Which of the following processes joins metals plastically?
    a. Friction welding
    b. Resistance welding
    c. Plasma welding
    d. All the above

6. Which electrode classification would be relevant to AWS A5.1-81?
    a. E 6013
    b. E 5133
    c. E 7018 - G
    d. Fleetweld 5

7. Which of the following coatings is associated with stove welding?
    a. Rutile
    b. Cellulosic
    c. Basic
    d. Oxidising

8. A common gas mixture used in MIG welding nickel alloys, to combine good levels of penetration with good arc stability would be:
    a. 100% CO2
    b. 100% argon
    c. 80% argon and 20% CO2
    d. 98% argon and 2% oxygen

9. Which type of SAW flux is more resistant to moisture absorption?
    a. Fused
    b. Agglomerated
    c. Basic
    d. All the above have the same resistance

10. The flame temperature of oxy/acetylene mixture gas is given as:

a. 3200°C
b. 2300°C
c. 5000°C
d. None of the above

11. A large grain structure in steels is said to produce:
a. Low ductility values
b. Low fracture toughness values
c. High fracture value values
d. High tensile strength

12. The likelihood of brittle fracture in steels will increase with:
a. A large grain formation
b. A reduction of in-service temperature to sub zero temperatures
c. Ferritic rather than austenitic steels
d. All the above

13. Repair welding is often more difficult than production welding due to:
a. The material being ingrained with in-service contaminants
b. Restricted access within the repair area
c. The possible position of the weld repair
d. All the above

14. Hydrogen cracking in the weld metal is likely when welding:
a. Carbon manganese steels
b. Stainless steels
c. Micro alloyed steels (HSLA)
d. Low carbon steels

15. EN 288 standard would refer to which of the following:
a. Welder approval testing
b. Welding equipment
c. Welding procedure approval
d. Consumables for welding

16. Porosity is caused by:
a. Entrapped slag in the solidifying weld
b. Entrapped gas in the solidifying weld
c. Entrapped metallic inclusions in the solidifying weld
d. None of the above

17. In a bend test the face of the specimen is in tension and the root is in compression. What type of test is being carried out?
a. A root bend test
b. A side bend test
c. A face bend test
d. None of the above

18. Ultrasonic testing is more advantageous in detecting which of the following weld imperfections, over other NDT methods?

a. Lack of sidewall fusion
b. Surface undercut
c. Incompletely filled groove
d. Overlap

19. Tempering is often carried out to regain toughness after which of the following processes?
a. Annealing
b. Normalising
c. Hardening
d. Stress relieving

20. The presence of iron sulphide in the weld metal is most likely to produce which of the following upon contraction of the weld?
a. Solidification cracking
b. Hydrogen cracking
c. Intergranular corrosion
d. Stress corrosion cracking

21. Austenitic stainless steel electrodes are generally smaller in length than mild steel electrodes because:
a. High amperage is used
b. Shelf life will be decreased
c. Their electrical conductivity is less than that of steel
d. They are more expensive

22. The voltage necessary to maintain an arc during metal arc welding is termed:
a. Mains supply voltage
b. Arc current
c. Arc voltage
d. Open circuit voltage

23. When MMA welding low carbon steel which electrode will give the greatest deposition rate?
a. Hydrogen controlled
b. Cellulosic
c. Rutile
d. Iron powder

24. Inherent rectification of the electrical output is produced in the arc when TIG welding using:
a. AC with a suppressor
b. AC without a suppressor
c. DC with reverse polarity
d. DC with straight polarity

25. Gamma rays and X-rays are part of a family of waves called:

a. Acoustic waves
b. Light waves
c. Electromagnetic waves
d. Transverse waves

26. A measure of the accuracy of a radiograph as an NDT tool is given by its:
a. Intensity
b. Density
c. Sensitivity
d. Exposure

27. A surface breaking crack will be detected during a magnetic particle inspection if it is:
a. At right angles to the lines of flux
b. Parallel to the lines of flux
c. At 25° to the lines of flux
d. All the above

28. The advantage of ultrasonic non-destructive testing for the examination of weldments is:
a. It can be used to locate flaws
b. It can be used to size flaws
c. It has a high sensitivity to planar flaws
d. All the above

29. Under normal contract conditions weld procedure approval tests for pipework are:
a. Mandatory
b. Dependant on site and weather conditions
c. Dependant upon the contractor's confidence in his procedures
d. Only required when MMA welding is used

30. Hydrogen controlled electrodes were developed principally for:
a. The prevention of porosity
b. The prevention of cracking
c. The enhancement of arc voltage
d. Their ease of arc starting

MULTICHOICE PAPER FIVE

1. Generally the most suitable method of detecting lack of sidewall fusion would be:
a. Ultrasonics.
b. MPI.
c. Radiography.
d. Penetrant inspection.

2. Hot shortness is a term used to indicate:
a. Lamellar tearing.
b. Solidification cracking.
c. Hydrogen cracking.
d. None of the above.

3. Cobalt as an isotope would generally be used on:
    - a. Thin material.
    - b. Tee joints.
    - c. Plate thicknesses greater than 25 mm.
    - d. All the above.

4. In welding procedure terms, a change in essential variable means:
    - a. Re-qualification of the weld procedure.
    - b. Possible changes in the weld's microstructure.
    - c. Possible changes in the mechanical properties.
    - d. All the above.

5. Weld symbols placed on a dotted line in accordance with ISO requirements means:
    - a. Weld on 'arrow' side.
    - b. Weld on 'other' side.
    - c. Weld on site.
    - d. Full penetration required.

6. A welding inspector's main attributes include:
    - a. Knowledge and experience.
    - b. Literacy.
    - c. Honesty and integrity.
    - d. All the above.

7. Technically, a code of practice is:
    - a. A standard.
    - b. A 'set of rules' for the manufacture of a product.
    - c. Related to welder and weld procedure approval.
    - d. All the above.

8. The correct term for 'cap height' is:
    - a. Reinforcement.
    - b. Cap profile height.
    - c. Excess weld metal.
    - d. All the above.
9. A tensile test will assess:
    - a. Impact values.
    - b. Stress.
    - c. Strain.
    - d. Both b and c.

10. The important point of high temperature steels is that:
    - a. They can withstand creep failure.
    - b. They may suffer re-heat cracking problems.
    - c. They may suffer loss of toughness.
    - d. All the above.

11. An austenitic stainless steel may suffer:

a. Weld decay.
b. Sensitisation.
c. Solidification cracking.
d. All the above.

12. Carbon equivalent values are useful to determine:
a. Weldability aspects.
b. Crack sensitivity aspects.
c. Typical mechanical properties.
d. All the above.

13. A basic electrode would normally:
a. Have superior mechanical properties.
b. Require baking before use.
c. Not be used on low carbon steels.
d. Both a and b.

14. When referring to TIG welding, the shielding gas could be:
a. Argon and hydrogen.
b. Argon and helium.
c. Argon and nitrogen.
d. All the above.

15. When referring to MIG welding, the shielding gas would be:
a. Argon.
b. Argon + 1% oxygen.
c. Argon + 20% carbon dioxide.
d. None of the above.

16. Submerged arc utilises:
a. Deep penetration characteristic.
b. High deposition rates on DC+.
c. Flat (PA) welding only.
d. None of the above.

17. Ultrasonics would be preferred over radiography due to:
a. Ability to find most defects.
b. Lower skill requirement.
c. Ability to detect laminations.
d. Both a and c.

18. The most serious defect types are:
a. Planar.
b. Cracks.
c. Lack of fusion.
d. All the above.

19. MMA welding of low alloy steels is more likely to be performed with:

a. Rutile electrodes.
b. Cellulosic electrodes.
c. Iron powder electrodes.
d. Basic hydrogen controlled electrodes.

20. Which of the following defects is more common to welds deposited by CO2 welding than welds deposited by MMA?
a. Slag inclusions.
b. Excess penetration.
c. Lack of sidewall fusion.
d. Tungsten inclusions.

21. Which defect would you expect to get in TIG welds in non-deoxidised steel?
a. Undercut.
b. Porosity.
c. Tungsten inclusions.
d. Linear misalignment.

22. Which of the following can arise from copper inclusions in a ferritic steel weld?
a. Weld metal cracks.
b. HAZ cracks.
c. Lamellar tearing.
d. Porosity.

23. Which of the following is likely to give the highest impact strength in ferritic weld metal?
a. Cellulosic electrodes.
b. Submerged arc with acid flux.
c. Spray transfer CO2 welding.
d. Basic coated MMA electrodes.

24. You suspect that ferritic steel plates contain cracks in the prepared edges. What NDT method would you use to check this?
a. Radiography.
b. Magnetic particle inspection.
c. Penetrant inspection.
d. Ultrasonic flaw detection.

25. Which of the following defects would you not expect to find by visual inspection of welds?
a. Linear slag inclusions.
b. Undercut.
c. Overlap.
d. Linear misalignment.

26. Stress relieving is not helpful in which of the following cases?
a. Improving resistance to stress corrosion cracking.
b. Improving dimensional stability after machining.
c. Lowering the peak residual stress.
d. Softening the steel.

27. What is the maximum hardness usually recommended for the heat-affected zone of a medium strength ferritic steel weld?
    a. 100 DP Hv.
    b. 350 DP Hv.
    c. 500 DP Hv.
    d. 750 DP Hv.

28. What effect does mid thickness laminations in steel plate normally have when they are located within a weld heat affected zone?
    a. Cause lamellar tearing.
    b. Fuse together to form a bond.
    c. Affect the weld metal composition.
    d. Cause internal tearing on a micro scale.

29. The permanent backing material for MMA welding of low carbon steel should be made from:
    a. Copper.
    b. Low carbon steel.
    c. QT steel.
    d. Cast iron.

30. The overall length of a pipeline can be affected by:
    a. Transverse shrinkage.
    b. Longitudinal shrinkage.
    c. Angular shrinkage.
    d. Circumferential shrinkage.

MULTICHOICE PAPER SIX

1. The weld dimension used to indicate the minimum strength of a fillet weld is:
    a. Leg length.
    b. Throat thickness.
    c. Width of bead.
    d. Length of weld element.

2. An electroslag weld requires what heat treatment to improve the grain structure?
    a. Annealing.
    b. Stress relieving.

   c. Normalising.
   d. Quench and tempering.

3. The most common type of failure associated with sharp fillets, notches and undercut is:
   a. Crystallisation.
   b. Fatigue.
   c. Corrosion.
   d. Brittle fracture.

4. Weld decay in stainless steels can be avoided by:
   a. Stress relieving.
   b. Slow cooling after welding.
   c. Addition of more manganese to the steel.
   d. Addition of titanium to the steel.

5. An eutectoid mixture in steel is:
   a. A mixture of ferrite and austenite.
   b. A mixture comprising a substitutinal solid solution.
   c. Called pearlite.
   d. Called ledeburite.

6. Low alloy steels having a high carbon equivalent before welding will require:
   a. A reduction in carbon content.
   b. High pre-heat temperatures.
   c. Low pre-heat temperatures.
   d. No pre-heating.

7. The electrodes for welding low alloy steels should be:
   a. Used with a low current value.
   b. One size larger than for general purpose electrodes.
   c. Used for welding in the flat position only.
   d. Heated in a drying oven before use.

8. The purpose of pre-heating low alloy steel pipes before electric arc welding is to:
   a. Refine grain structure.
   b. Relieve internal stress.
   c. Retard rapid cooling.
   d. Regulate excessive expansion.

9. Welder qualification tests are designed to:
   a. Test the correctness of the welding procedure.
   b. Test the welder's skill.
   c. Prove the weldability of the parent material.
   d. All the above.

10. In positional MMA welding on pipework, welders are having difficulty in obtaining good capping profiles when welding in the overhead position. Would you:
   a. Advise them to increase the current.
   b. Advise them to increase the voltage.
   c. Ask for a new welding team.

d. Suggest the use of a smaller diameter electrode.

11. You have a macro section of a 'T' butt joint that shows a step-like defect lying outside the visible HAZ. What would this defect possibly signify?
    a. HAZ cracking.
    b. Toe cracking.
    c. Lamination.
    d. Lamellar tearing.

12. Which electrode deposits weld metal with the greatest ductility and resistance to cracking?
    a. Rutile.
    b. Cellulosic.
    c. Basic.
    d. Oxidising.

13. Which one of the following is not helpful in minimising angular distortion during welding?
    a. Use of double 'V' weld prep using balanced welding technique.
    b. Pre-setting of work piece.
    c. Applying post weld heat soak.
    d. Changing from a single 'V' prep for thick material.

14. Argon purging on the root side is necessary in the TIG welding of stainless steel to:
    a. Obtain full penetration.
    b. Obtain full fusion.
    c. Avoid porosity in the root.
    d. Obtain a satisfactory weld surface finish.

15. Which of the following can arise from copper inclusions in a mild steel weld?
    a. Weld metal cracks.
    b. HAZ cracks.
    c. Lack of fusion.
    d. Porosity.

16. Stress relief is not helpful in which of the following cases?
    a. In improving resistance to stress corrosion.
    b. In improving dimensional stability after machining.
    c. In lowering the peak residual stresses.
    d. In softening the metal.
17. Stray arc strikes are undesirable since they:
    a. Leave a poor surface finish.
    b. Cause weld metal cracking.
    c. Reduce corrosion resistance.
    d. Cause local hardening and cracking in the parent material.

18. Cold cracking is most likely to occur in a weldment if:
    a. The rate of cooling is too fast.
    b. The rate of cooling is too slow.
    c. It lacks ductility at high temperatures.
    d. Impurities are present at its grain boundaries.

19. Chromium, when added to steel as an alloying element, has the effect of making the alloy more:
    a. Ductile.
    b. Plastic.
    c. Hardenable.
    d. Malleable.

20. When depositing weld metal, fusion will take place at the sides of the joint resulting in an admixture between weld metal and parent metal. This alloying effect is known as:
    a. Diffusion.
    b. Absorption.
    c. Dilution.
    d. Migration.

21. Percentage elongation of a metal undergoing a tensile test is a measure of:
    a. Elasticity.
    b. Plasticity.
    c. Ductility.
    d. Malleability.

22. When a longitudinal load is put on a lap joint, the stress set up is normally:
    a. Shear stress.
    b. Tensile stress.
    c. Compressive stress.
    d. Residual stress.

23. When a metal is subjected to a fluctuating load, a condition of cyclic stressing can be set up, which eventually can result in structural breakdown known as:
    a. Tensile failure.
    b. Fatigue failure.
    c. Yield failure.
    d. Shear failure.

24. What happens to the mechanical properties of steel if the carbon content is increased to 0.5%?
    a. The material becomes softer.
    b. Malleability is increased.
    c. The tensile strength is increased.
    d. Ductility is increased.

25. Columnar growth takes place when a metal is:
    a. Cold.
    b. Losing heat.
    c. Being heated.
    d. Being rolled.

26. If a low carbon steel pipe has to carry a liquid, care must be taken when making the butt welds to ensure penetration is not excessive because it:
    a. Reduces the flow rate of the liquid.
    b. May increase the rate of corrosion.
    c. Can contaminate the liquid.
    d. May cause excessive pipe wear.

27. When a steel suffers hot shortness, it is mostly due to the presence of:
    a. Sulphur.
    b. Phosphorous.
    c. Silicon.
    d. Manganese.

28. When a steel is heated to above its upper critical temperature, the structure produced is:
    a. Martensite.
    b. Austenite.
    c. Pearlite.
    d. Sorbite.

29. The type of crystal normally found in a single run arc weld in the as welded condition is:
    a. Equi-axed.
    b. Polycrystalline.
    c. Dendritic.
    d. Columnar.

30. The first sub-zone in the heat affected zone of the parent metal nearest the weld deposit will consist of:
    a. Large crystal grains.
    b. Small crystal grains.
    c. Elongated crystal grains.
    d. Distorted crystal grains.

MULTICHOICE PAPER SEVEN

1. Pipe welding codes are set up by:
    a. Welding operators.
    b. State governments.
    c. Associations, societies, insurance companies, manufacturers and the military.
    d. Construction unions.

2. The different grain structure between the weld deposit and the base metal can be determined by:
    a. A face bend test.
    b. A root bend test.
    c. A hardness test.

   d. An etching test.

3. A root bend test is used to test the amount of weld:
   a. Ductility.
   b. Elongation.
   c. Hardness.
   d. Penetration.

4. What would be observed if a fillet weld were sectioned and macro-etched?
   a. The grain of the other beads is coarser than the final bead.
   b. The penetration and fusion into the root is very deep.
   c. Each bead appears to be distinctly separated from the adjoining beads.
   d. The grain structure remains the same in all passes.

5. What is the most common cause of failure in root bend tests?
   a. Too high a current setting.
   b. Too long a pause in the down cycle of the weave.
   c. Lack of fusion and penetration.
   d. Too high a travel speed.

6. The purpose of a nick break specimen is to provide a test for:
   a. Tensile strength and fracture appearance.
   b. Ductility and fracture appearance.
   c. Elongation and fracture appearance.
   d. Soundness and fracture appearance.

7. Which organisation publishes the most commonly used code for boiler and pressure vessel welding?
   a. American Welding Society.
   b. American Society of Mechanical Engineers.
   c. American Petroleum Institute.
   d. American National Standards Institute.

8. A low hydrogen electrode, according to BS 639, would contain:
   a. No hydrogen.
   b. Less than 15 ml of hydrogen per 100 grams of deposited weld metal.
   c. Between 15 ml and 25 ml of hydrogen per 100 grams of deposited weld metal.
   d. Less than 25 ml of hydrogen per 100 grams of deposited weld metal.

9. The second run in a three run butt weld using the stovepipe technique is known as the:
   a. Filling run.
   b. Hot pass.
   c. Intermediate run.
   d. Sealing run.

10. You could determine that an electrode is cellulosic by its:

- a. BS 639 coding.
- b. Colour.
- c. Trade name.
- d. BS 499 coding.

11. Which type of electrode coating gives the most voluminous gas shield?
    - a. Rutile.
    - b. Basic.
    - c. Oxidising.
    - d. Cellulosic.

12. Which of the following steels is likely to be more susceptible to hydrogen cracking?
    - a. Carbon equivalent of less than 0.25 %.
    - b. Carbon equivalent of 0.35%.
    - c. Carbon equivalent of 0.38%.
    - d. Carbon equivalent of 0.43%.

13. Preheating and interpass heating are used primarily for:
    - a. Aiding fusion.
    - b. Reducing hydrogen content of weld preparation prior to welding.
    - c. Ensure a fine grain size.
    - d. Slow down the cooling rate after welding.

14. Submerged arc welds made with re-cycled flux are liable to:
    - a. Porosity.
    - b. Course grain size.
    - c. Undercut.
    - d. Incomplete penetration.

15. Incomplete penetration in a single 'V' butt joint could be caused by:
    - a. Too large a root gap.
    - b. Too small a root gap.
    - c. Too high a heat input.
    - d. Too small a root face.

16. In submerged arc welding, which of the following width to depth ratios would be likely to result in solidification cracking?
    - a. 1 : 3.
    - b. 3 : 1.
    - c. 2 : 1.
    - d. 1 : 1.

17. You are responsible for controlling welding on site. A large incidence of porosity has been reported in recent welding. Would you investigate?
    - a. The electrode type.
    - b. Power source.
    - c. Electrode storage.
    - d. Day temperature.

18. The main reason why all adhering scale should be removed when the pipe end preparation is made by oxy-gas cutting is?
    - a. Oxidisation of the weld metal is minimised.
    - b. The speed of welding is increased.
    - c. Pipe bore alignment is made easier.
    - d. Reduction of the weld deposit is prevented.

19. When manual metal arc welding low carbon steel, which electrode covering will give the greatest degree of penetration?
    - a. Iron powder.
    - b. Rutile.
    - c. Cellulosic.
    - d. Low hydrogen.

20. When tungsten arc gas shielded welding stainless steel, which one of the following should be used?
    - a. Alternator.
    - b. A. C. transformer.
    - c. D. C. generator.
    - d. Constant potential rectifier.

21. Which gas shroud should be used when tungsten arc gas shielded welding aluminium alloys?
    - a. Nitrogen.
    - b. Carbon dioxide.
    - c. Argon/carbon dioxide mixture.
    - d. Argon.

22. The most common type of defect found in a structure when it is undergoing service is:
    - a. Fatigue cracking.
    - b. Crystallisation.
    - c. Weld decay.
    - d. Stress fracture.

23. In the examination of a welded aluminium joint, macro etching may reveal:
    - a. Lack of inter-run penetration.
    - b. Carbon pick-up.
    - c. Weld decay.
    - d. Micro cracks.

24. MMA welds made with damaged electrode coatings are subject to:
    - a. Porosity.
    - b. Undercut.
    - c. Excessive penetration.
    - d. Excessive bead height.

25. Which physical test is more likely to reveal HAZ embrittlement?
    a. Transverse tensile.
    b. All weld tensile.
    c. Root bend.
    d. Charpy impact.

26. Which of the following destructive tests is not normally required for welder approval?
    a. Bend tests.
    b. Macro examination.
    c. Impact tests.
    d. Fracture tests.

27. Too large a diameter of filler rod should not be used to make a welded joint because:
    a. Excess reinforcement profile will be difficult to obtain.
    b. The included bevel angle will have to be reduced.
    c. Root fusion may be difficult to obtain.
    d. The gap setting will have to be changed.

28. If pipe bores are not matched correctly it can result in:
    a. Lack of root penetration.
    b. Incorrect gap setting.
    c. Excessive root faces.
    d. Overheating during welding.

29. A correctly made tack weld should slope from the middle to the ends in order to:
    a. Aid better penetration at the join-up.
    b. Prevent porosity at the join-up.
    c. Reduce the electrode size required.
    d. Reduce the overall consumable consumption.

30. Two low carbon steel pipes, 150mm diameter and 6mm wall thickness, are to be butt welded using the TIG process. To ensure a full strength joint, which of the following preps is most suitable?
    a. Open single bevel.
    b. Open single Vee.
    c. Open square preparation.
    d. Closed square preparation.

PROPERTIES OF MATERIALS

1. The ability of a material to withstand a load pulling it apart is called its _______ _______.

2. The ability of a material to be stretched out without breaking is called _______.

3. An Izod impact machine is used to give indication of the _______ of a material.

4. The ability to withstand indentation is called _______.

5. Lack of ductility is called _______.

6. The property of a metal to return to its original shape is called _______.

7. Increase in carbon content causes an _______ in strength and hardness.

8. When carbon percentage increases, there is a decrease in _______.

9. Low carbon steel contains less than _______ carbon.

10. Low ductility in a weld metal could result in _______.

11. Alloying is used to _______ mechanical and physical properties of a steel.

12. Sulphur and phosphorus are not alloying elements; they are _______.

13. Alloying allows designers to use _______ sections and still have the same strength.

14. An alloy that contains a high percentage of chromium and nickel would have resistance to _______.

15. Quenching a carbon or low alloy steel will result in an _______ in hardness and a _______ in ductility.

16. The hard constituent that results when steel is quenched is called _______.

17. The tough laminated structure that is formed on slow cooling of ferrite and iron carbide (cementite) is called _______.

18. The amount of martensite formed depends on the speed of _______ and the percentage of _______.

19. After quenching, the structure may be improved by reheating to 200-300°C. This is called ________.

20. Small percentages of chromium will increase the strength and _______, while a small percentage of nickel will increase _______.

ANSWERS

PAPER ONE

1.	d	2.	d	3.	b	4.	c	5.	c	6.	b	7.	c
8.	a	9.	c	10.	a	11.	d	12.	a	13.	b	14.	b
15.	c	16.	a	17.	a	18.	b	19.	a	20.	d	21.	c
22.	a	23.	d	24.	c	25.	d	26.	d	27.	c	28.	b
29.	b	30.	b										

PAPER TWO

1.	b	2.	a	3.	b	4.	d	5.	c	6.	c	7.	d
8.	d	9.	d	10.	d	11.	b	12.	b	13.	c	14.	b

15. c	16. b	17. b	18. c	19. b	20. c	21. b
22. d	23. c	24. b	25. c	26. c	27. b	28. b
29. d	30. b					

PAPER THREE

1. d	2. a	3. d	4. d	5. d	6. c	7. b
8. d	9. d	10. d	11. d	12. d	13. b	14. d
15. d	16. d	17. b	18. d	19. a	20. d	21. d
22. d	23. d	24. c	25. d	26. d	27. d	28. b
29. c	30. b					

PAPER FOUR

1. c	2. b	3. c	4. b	5. a	6. a	7. b
8. b	9. a	10. a	11. b	12. d	13. d	14. c
15. c	16. b	17. c	18. a	19. c	20. a	21. c
22. c	23. d	24. b	25. c	26. c	27. a	28. d
29. a	30. b					

PAPER FIVE

1. a	2. b	3. c	4. d	5. b	6. d	7. b
8. c	9. d	10. d	11. d	12. d	13. d	14. d
15. a	16. a	17. d	18. d	19. d	20. c	21. b
22. a	23. b	24. b	25. a	26. b	27. b	
28. a	29. b	30. b				

PAPER SIX

1. b	2. c	3. b	4. d	5. c	6. b	7. d
8. c	9. b	10. d	11. d	12. c	13. c	14. c
15. a	16. b	17. d	18. a	19. c	20. c	21. c
22. a	23. b	24. c	25. b	26. a	27. a	28. b
29. d	30. a					

PAPER SEVEN

1. c	2. d	3. a	4. c	5. c	6. d	7. b
8. b	9. b	10. a	11. d	12. d	13. b	14. a
15. b	16. a	17. c	18. a	19. c	20. c	21. d
22. a	23. a	24. a	25. d	26. c	27. c	28. a
29. a	30. b					

PROPERTIES OF MATERIALS

1. Tensile Strength.	2. Ductility.	3. Toughness.	4. Hardness.
5.Brittleness.	6. Elasticity.	7. Increase.	8. Ductility.

9.0.2%

10. Cracking.

11. Increase.

12. Impurities.

13. Smaller/Thinner.

14. Corrosion.

15.Increase....Decrease

16.Martensite.

17.Pearlite.

18. Cooling....Carbon.

19.Tempering.

20. Hardness....Toughness.