Section 4

Destructive Testing

1 Introduction

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

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

Destructive tests can be divided into two groups:

- Those used to measure a mechanical property – **quantitative tests**
- Those used to assess the joint quality – **qualitative tests**

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

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

2 Test Types, Test Pieces and Test Objectives

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

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

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

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

2.1 Transverse tensile tests

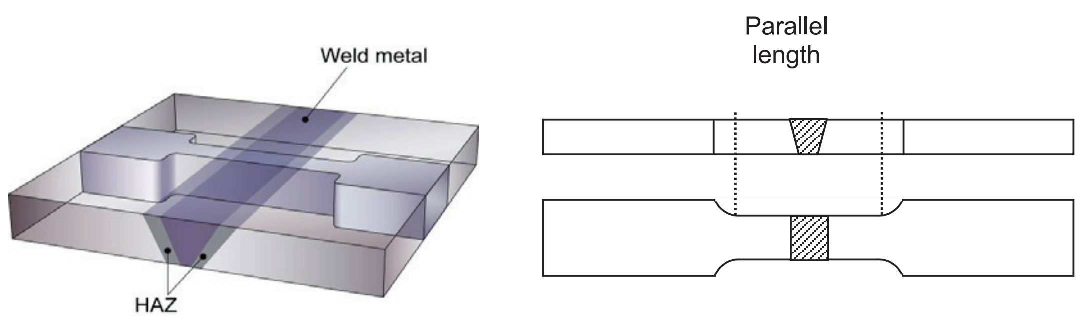
Test objective

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

Test specimens

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

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



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

Test method

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

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

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

Acceptance criteria

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

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

2.2 All-weld tensile tests

Test objective

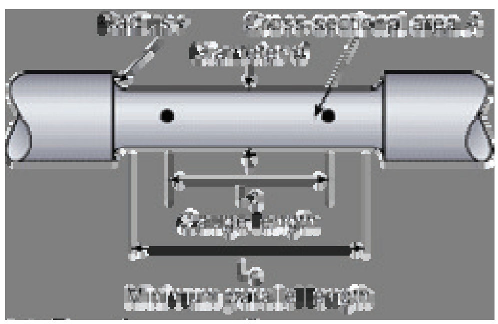
There may be occasions when it is necessary to measure the weld metal strength as part of welding procedure qualification – particularly for elevated temperature designs.

The test is carried out in order to measure tensile strength and also yield (or proof strength) and tensile ductility.

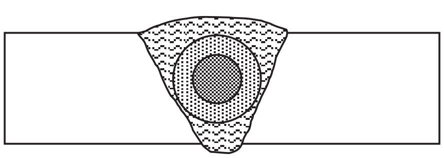
All-weld tensile tests are also regularly carried out by welding consumable manufacturers to verify that electrodes and filler wires satisfy the tensile properties specified by the standard to which the consumables are certified.

Test specimens

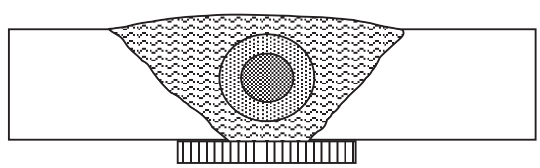
As the name indicates, test specimens are machined from welds parallel with their longitudinal axis and the specimen gauge length must be 100% weld metal.



Round cross section



Round tensile specimen from a welding procedure qualification test piece



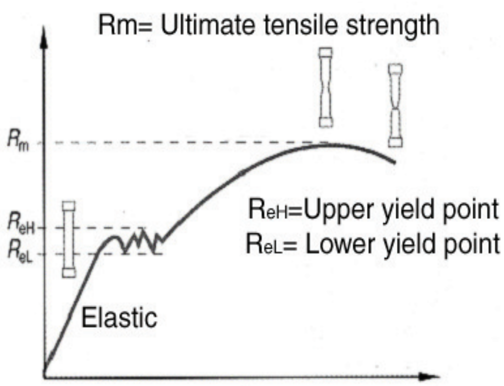
Round tensile specimen from an electrode classification test piece

Test method

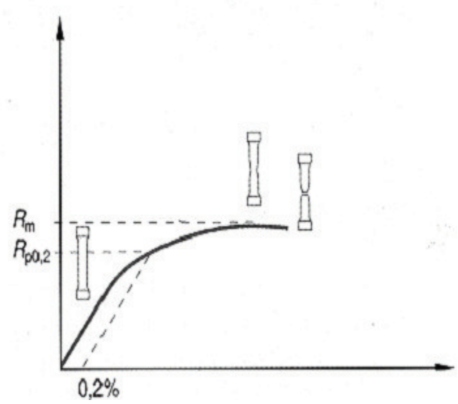
Specimens are subjected to a continually increasing force in the same way that transverse tensile specimens are tested.

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

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



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

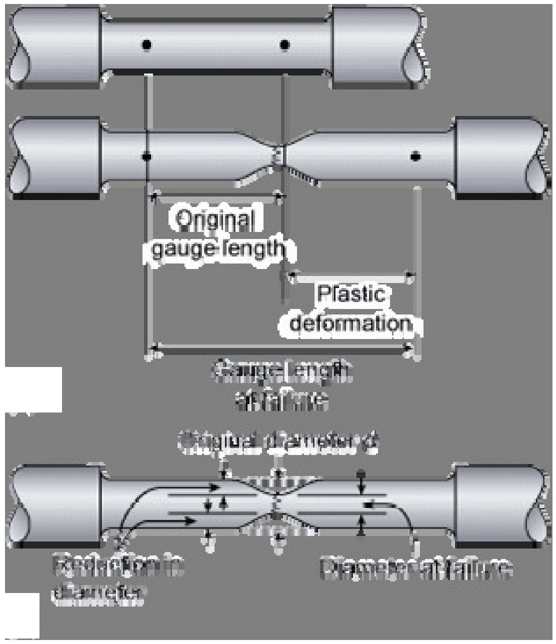


Load-extension curve for a steel (or other metal) that does not show a distinct yield point; proof stress is a measure of the elastic limit

Tensile ductility is measured in two ways:

- Percent elongation of the gauge length
- Percent reduction of area at the point of fracture

The figure below illustrates these two ductility measurements.



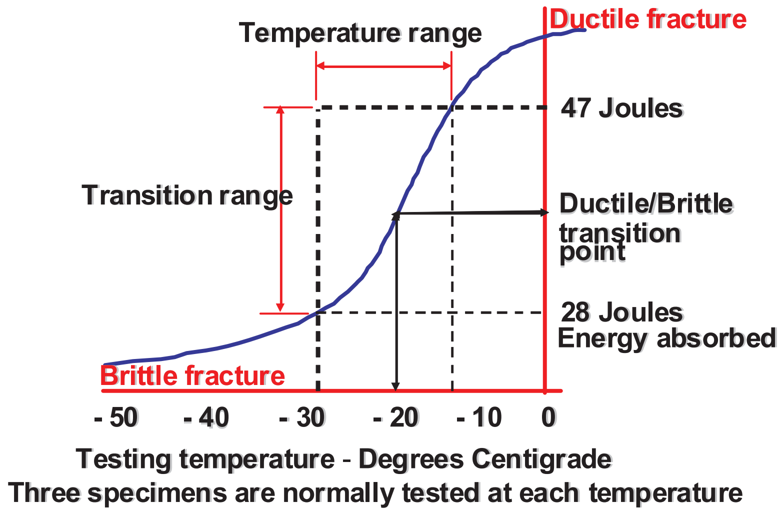
2.3 Impact toughness tests

Test objective

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

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

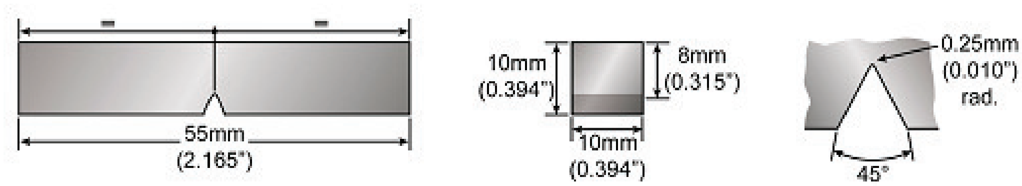
C-Mn and low alloy steels undergo a sharp change in their resistance to brittle fracture as their temperature is lowered so that a steel that may have very good toughness at ambient temperature may show extreme brittleness at sub-zero temperatures – as illustrated in following figure.



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

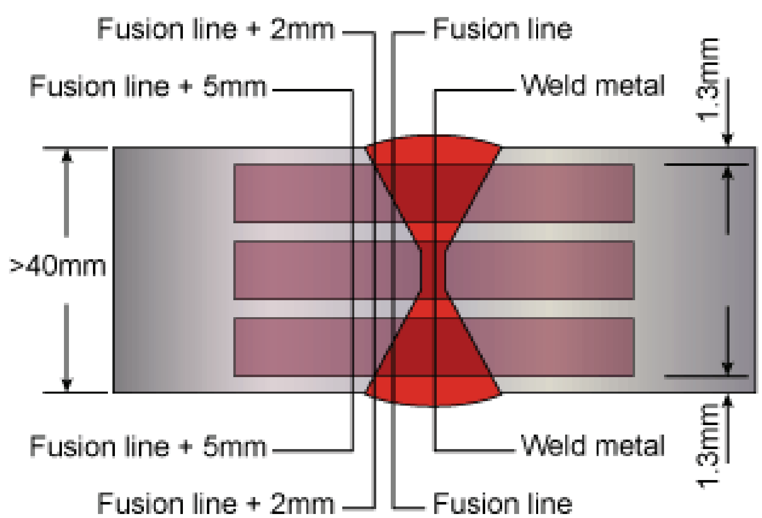
Test specimens

The dimensions for test specimens have been standardised internationally and are shown below for **full sized specimens**. There are also standard dimensions for smaller sized specimens, for example 10x7.5mm and 10x5mm.



Charpy V notch test piece dimensions for full sizes specimens

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



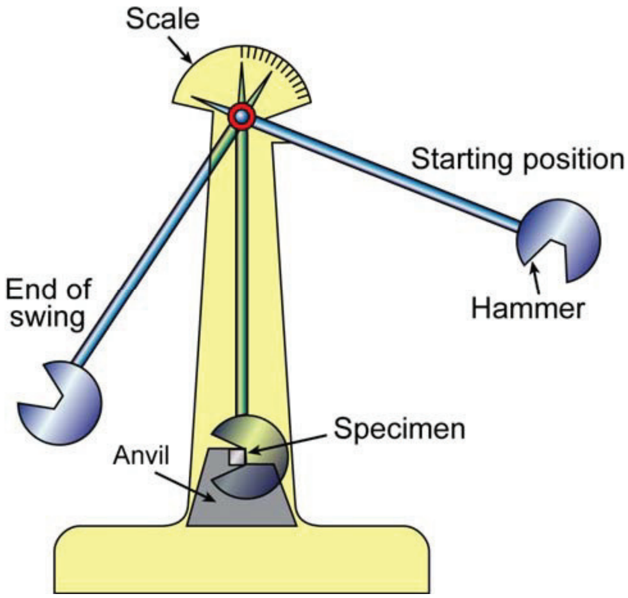
Typical notch positions for Charpy V notch test specimens from double V butt welds

Test method

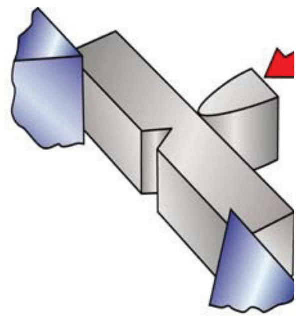
Test specimens are cooled to the specified test temperature by immersion in an insulated bath containing a liquid that is held at the test temperature.

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

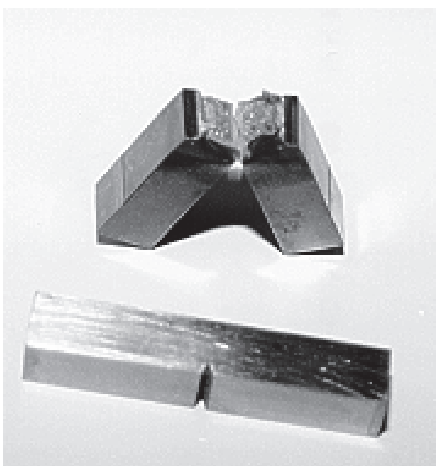
The main features of an impact test machine are shown below.



Impact testing machine



Impact specimen on the anvil showing the hammer position at point of impact.



Charpy V notch test pieces before and after testing

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

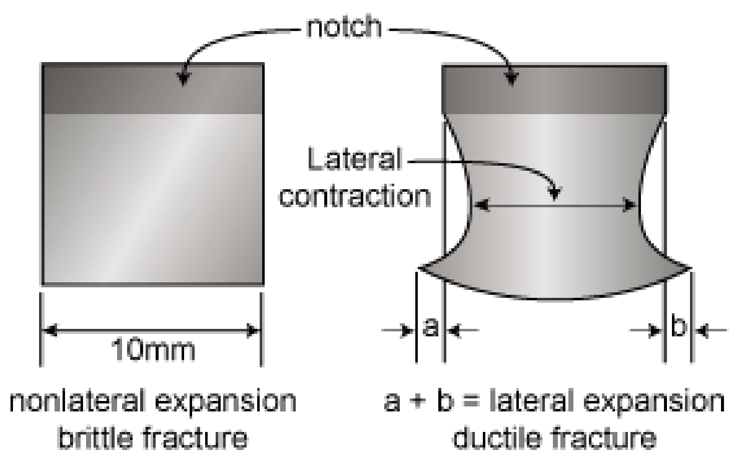
Impact test specimens are taken in triplicate (three specimens for each notch position) as there is always some degree of scatter in the results - particularly for weldments.

Acceptance criteria

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

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

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



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

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

2.4 Hardness testing

Test objective

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

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

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

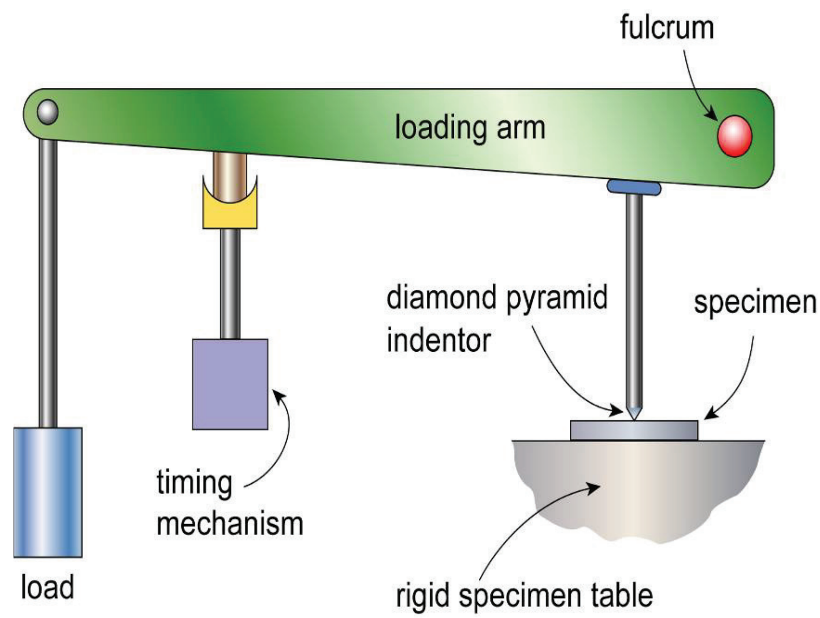
Test methods

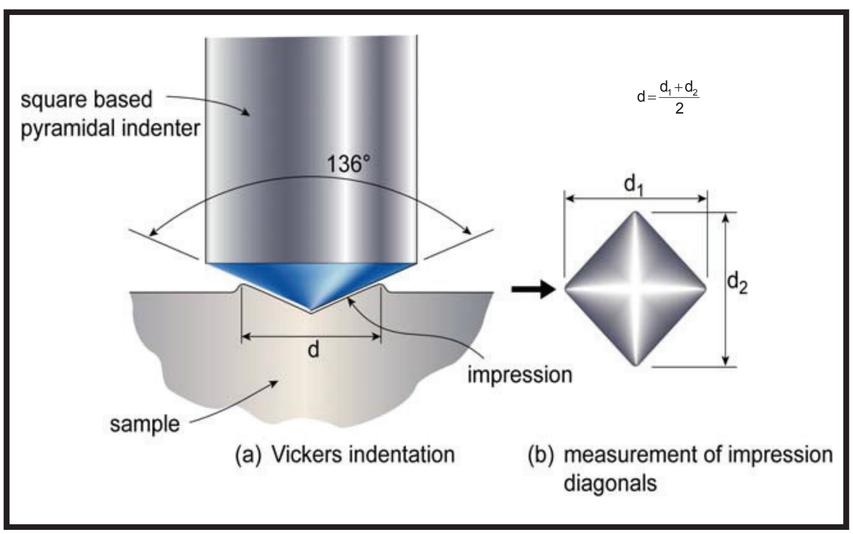
There are three widely used methods for hardness testing:

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

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

The Vickers method of testing is illustrated below.



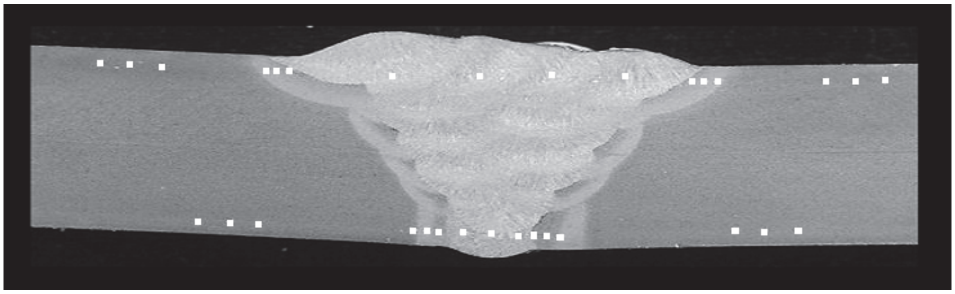


Both the Vickers and Brinell methods are suitable for carrying out hardness surveys on specimens prepared for macroscopic examination of weldments.

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

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

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



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

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

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

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

2.5 Crack tip opening displacement (CTOD) testing

Test objective

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

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

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

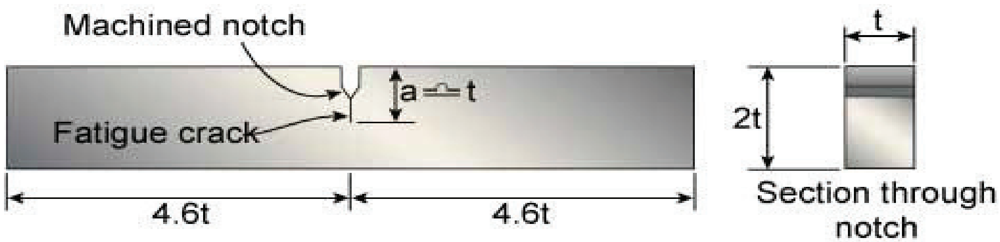
This data is essential for making an appropriate decision when a crack is discovered during inspection of equipment that is in-service.

Test specimens

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

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

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



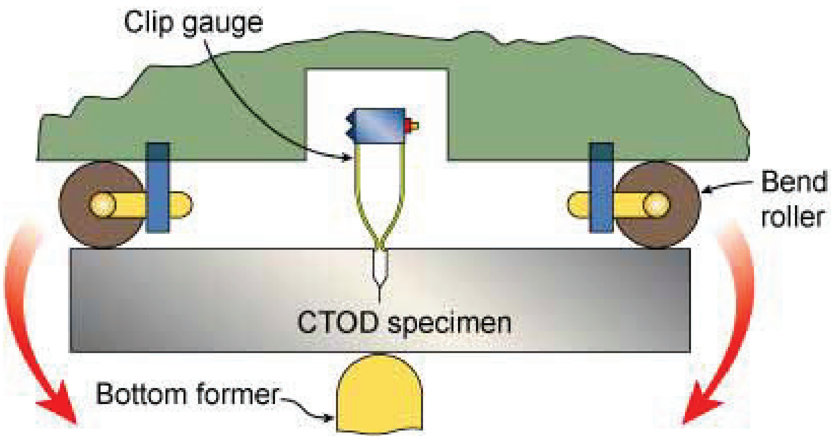
Test method

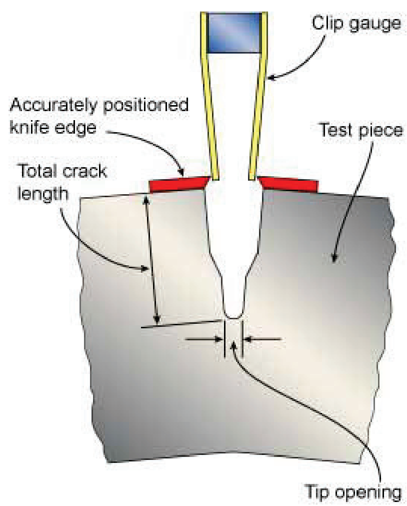
CTOD specimens are usually tested at a temperature below ambient and the specimen temperature is controlled by immersion in a bath of liquid that has been cooled to the required test temperature.

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

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

The figures below illustrate the main features of the CTOD test.





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

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

Acceptance criteria

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

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

CTOD values are expressed in millimetres - typical values might be <<~0.1mm = brittle behaviour; >>~1mm = very tough behaviour.

2.6 Bend testing

Test objective

Bend tests are routinely taken from welding procedure qualification test pieces and sometimes on welder qualification test pieces.

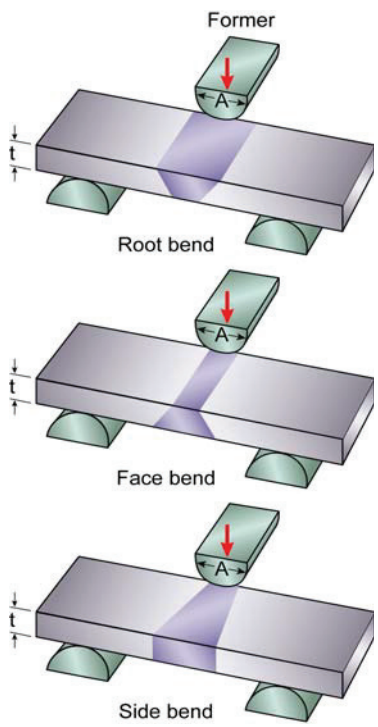
Subjecting specimens to bending is a simple method of verifying there are no significant flaws in the joint. Some degree of ductility is also demonstrated.

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

Test specimens

There are four types of bend specimen:

- **Face:** Specimen taken with axis transverse to butt welds up to ~12mm thickness and bent so that the face of the weld is on the outside of the bend (face in tension).
- **Root:** Test specimen taken with axis transverse to butt welds up to ~12mm thickness and bent so that the root of the weld is on the outside of the bend (root in tension).
- **Side:** Test specimen taken as a transverse slice (~10mm) from the full thickness of butt welds >~12mm and bent so that the full joint thickness is tested (side in tension).
- **Longitudinal bend:** Test specimen taken with axis parallel to the longitudinal axis of a butt weld; specimen thickness is ~12mm and the face or root of weld may be tested in tension.



Test method

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

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

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

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

The standard that specifies the test method will specify the minimum bend angle that the specimen must experience and this is typically 120-180^0.

Acceptance criteria

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

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

2.7 Fracture tests

2.7.1 Fillet weld fractures

Test objective

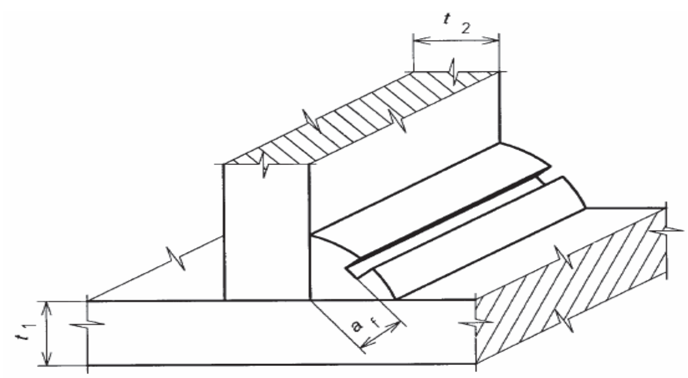
The quality/soundness of a fillet weld can be assessed by fracturing test pieces and examining the fracture surfaces.

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

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

Test specimens

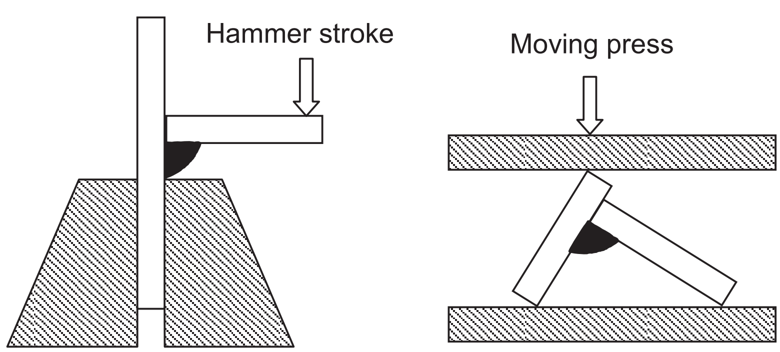
A test weld is cut into short lengths (typically ≥50mm) and a longitudinal notch is machined into the specimen as shown below. The notch profile may be square, V or U shape.



Longitudinal notch in fillet welds

Test method

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



Acceptance criteria

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

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

2.7.2 Butt weld fractures (nick-break tests)

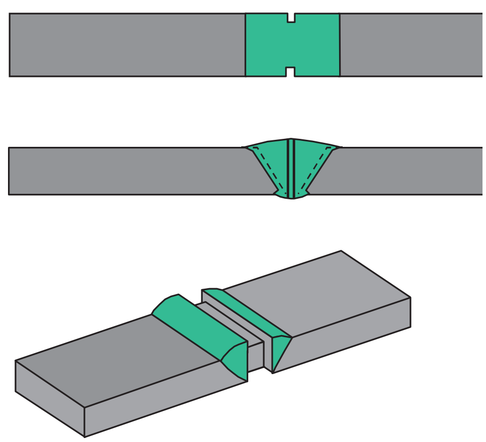
Test objective

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

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

Test specimens

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



Test method

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

Acceptance criteria

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

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

3 Macroscopic Examination

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

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

3.1 European Standards for destructive test methods

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

EN 875	Destructive tests on welds in metallic materials – Impact tests – test specimen location, notch orientation and examination.
EN 895	Destructive tests on welds in metallic materials – transverse tensile test.
EN 910	Destructive tests on welds in metallic materials – bend tests.
EN 1321	Destructive tests on welds in metallic materials – macroscopic and microscopic examination of welds.
BS EN 10002	Metallic materials - Tensile testing. Part 1: Method of test at ambient temperature.
BS EN 10002	Tensile testing of metallic materials. Part 5: Method of test at elevated temperatures.