TESTING OF WELDS IN FERROUS METALS

by L.N. Pussegoda, C.B. Ratnayake and A. Alvapillai

Introduction

A significant factor in selecting an engineering material is its ease of welding. There are many welding processes; metal arc-welding (shielded, submerged, M.I.G. and T.I.G.), electro-slag welding, resistance welding (spot, seam and projection), and gas welding are some. Locally the most commonly used processes are the shielded metal arc (known as arc-welding) and gas welding.

Welding is used in both fabrication and repair. In almost all cases a welded joint has to carry a service load. Quantitatively the load will depend on the design, but may be classified broadly to two types:

(i) carrying the full load on the base metal, or
(ii) carrying a part of the load on the base metal.

Therefore the quality (or soundness) and strength of a weld is of primary importance, especially in the first case.

When considering the quality and strength of a welded joint (weldment) the following factors play a major role.

(i) Joint design
(ii) Distortion and residual stresses due to welding.
(iii) Weldability of the base metal.
(iv) Weld defects; lack of penetration, weld profile defects (notches), porosity, slag inclusions, and cracks.
(v) Mechanical properties of the weld metal and the heat affected zone (HAZ).

All these factors have their own important significant effects and must be ideally considered when designing and producing a welded joint. Finally the weldment must be checked for reliability (i.e. safety) and performance in the service conditions. This may be done by testing the weldment.

There is an extremely large number of methods to test welds.

These can vary from a simple tensile or a bend test on the weldment sample to a full scale fatigue test on an aircraft wing or a nuclear reactor. In selecting the method consideration must be given to factors such as:

(i) degree of reliability,
(ii) testing facilities and time available,
(iii) economic aspects (i.e. cost of failure, cost of testing),
(iv) failure criterion of the design, and
(v) damage to life and property.

The aim of this paper is to improve the awareness of the local engineer on the more commonly performed tests and their uses and limitations. For the specific techniques and details the reader is referred to other sources.

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Methods for Testing Weldments

A weldment consist of 3 different regions,

(i) weld metal,
(ii) heat affected zone (HAZ), and
(iii) base metal.

These 3 regions can be tested separately or as one unit using a sample, while a full scale test is done on the completed component/structure.

Methods for testing different regions of a weldment

(i) All weld tensile test.

This test will determine the tensile properties (i.e., yield and tensile strength and elongation) of the weld metal. The specimen must be machined from the weld metal, see Fig. 1. In all cases the total gauge length of the specimen must be machined within the weld metal. Hence small welds cannot be tested. For details (i.e. specimen size, testing technique, determination of results etc) see pages 9.6 to 9.8 in reference 1, and pages 12 and 13 in reference 2.

(ii) All weld impact test.

This test will give a measure of the toughness of the weld metal. The specimen must be machined so that the V-notch and the surrounding metal contains only the weld metal, see Fig. 1. In the Izod impact test the energy absorbed at room temperature is determined. In the charpy V-notch test, from the variation of energy with testing temperature the duclite to brittle fracture transition temperature can be determined. Small welds can be tested as the fracture patch can be directed through the weld metal. For details see pages 273-289 in reference 3.

(iii) Testing the HAZ

HAZ is the most complicated region. It consist of a range of microstructures due to reheating of the base metal to different 'peak temperatures' during welding. However, the critical region is adjacent to the fusion line, i.e. the coarse grain heat affected zone (CGHAZ) where the weldment usually has its lowest toughness. Therefore the lowest toughness of the HAZ may be measured by locating the V-notch of the specimen adjacent to the fusion line (see Fig. 1) in order to ensure that the fracture follows the path of least resistance. For details see pages 392, 393 and 398 in reference 3. Interpretation of results from a tensile test of the HAZ is complicated due to the range of microstructures in this region.

These test methods determine the mechanical properties of the weld metal and the HAZ. In the following section the weldment is tested as a unit and hence determine mechanical properties in the presence of any weld defects.

Methods of testing the weldment

(i) Tensile test

The tensile test specimen contains the entire weldment (i.e. weld metal, HAZ and base metal). The two standard specimens are the transverse and the longitudinal (see Fig. 2), and determine the tensile strength of the weldment in the two directions. Hence results may be used quantitatively in determining the design stresses. However, as only a very small portion of the weldment is tested the tensile strength obtained may not represent the weakest regions of the weldment. Details of the transverse test specimen is given in page 9.12 of reference 1, and pages 8 and 9 in reference 2, while for the longitudinal specimen see page 4.5 in reference 4.

(ii) Bend test

The object of this test is to determine the ductility of the weldment. In the guided bend test a specimen containing the weldment, is bent around a former of specified diameter (usually determined by thickness of specimen) without impact loading. There is a number of test methods with corresponding specimens, and details are given in pages 9.9 to 9.12 of reference 1, pages 14 to 19 in reference 2, and pages 339 to 402 in references 3. In the free bend test there is no control of the bend diameter (compared to the guided bend test), and details are given in pages 9.15 to 9.18 of reference 1. In these too the test specimen may not represent the weakest regions of the weldment.

(iii) Full scale testing

The most common method is proof testing. The welded component/structure is tested for serviceability by applying the designed load multiplied by a service factor. Therefore the complete weldment is tested and hence is a versatile method. A typical example is the proof testing of pressure vessels fabricated by welding. For details see pages 6.62 and 6.63 in reference 4.

Non-destructive testing (NDT)

NDT methods may be used to detect, locate, and determine the size of weld defects, and therefore characteristically differs from the earlier test methods. As in proof testing the actual weldment can be tested, while the other methods use samples of the weldment.

(i) Visual inspection

Is a macro-examination (a single lens magnifying glass may be used) to detect and locate defects such as surface cracks, discontinuity of the weld, defects in weld size and profile; undercut, overlap, insufficient penetration etc.

(ii) Penetrant inspection

Detects and locates minute discontinuities that are open to the surface; cracks and pores. Employs a penetrating liquid (Dye or Fluorescent) which when applied over the surface enters the discontinuities. After the excess penetrant has been cleaned off the surface, the penetrant which exudes is observed indicating the presence and location of the discontinuity. For details see page 303 to 321 in reference 5.

(iii) Magnetic particle inspection

Detects surface and sub-surface discontinuities in magnetic materials; cracks, inclusions, porosity and incomplete fusion. When a magnetic field is established in a ferro-magnetic material containing discontinuities in the path of magnetic flux, minute poles are set up which have a stronger attraction for magnetic particles. For details see pages 686 to 727 in reference 5.

(iv) Radiographic inspection

Locates and determines the size

of discontinuities in the interior of weldments by using short wavelength radiation (X-rays/ γ- rays). The degree of absorbtion is a function of density and thickness of the metal. Consequently there will be a variation in the absorbtion of rays in the presence of discontinuities, and can be observed in a radiograph. Detectable defects on a radiograph is in the range 0.5 to 2% of thickness of the metal. Defects that may be detected are slag inclusions, porosity, cracks, inadequate penetration and incomplete fusion. For details see pages 169 to 184 and 451 to 455 in reference 5.

(v) Ultrasonic inspection

Uses high frequency sound waves to detect, locate and determine the size of discontinuities. An electrical signal is converted to vibrations or sound by a transducer and introduced to the weldment via a liquid couplant. The signal is reflected when intercepted by a discontinuity and picked up by the transducer and recorded in a chart drive or CRO. The degree of reflection is dependent on the nature (eg. solid/air, metallic/non metallic), orientation and size of the discontinuity. Therefore as in radiographic inspection knowledge on the nature, orientation and location is useful in optimizing the results Further details are given in pages 265 to 302 and 369 to 372 in reference 5.

Conclusions

The testing methods given in this paper may be separated into two categories;

(i) Destructive testing where the strength and toughness of the weldment is determined.

(ii) Non-destructive testing where defects are detected, located and their sizes determined.

By the first method we could determine a design stress, while in the second method we could arrive at a recommended quality level (see pages 369 to 372 and 451 to 455 in reference 5). However, the first method has the limitation that the complete weld cannot be tested, while in the second method this is possible.

References

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3. ASTM Standards 1980, Part 10, American Society for Testing of Materials, Philadelphia, U.S.A., 1980.
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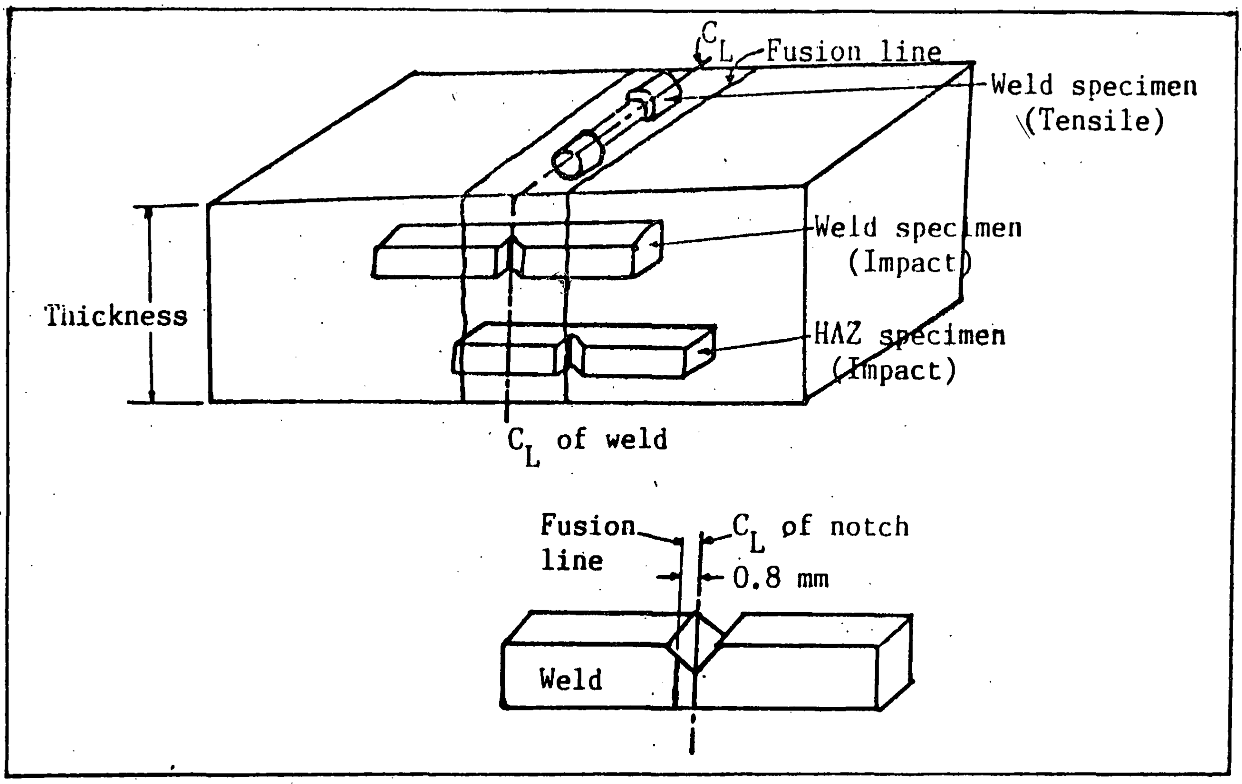

Fig. 1. Location of Test Specimens Within Weld and Heat-Affected-Zone (HAZ) Test Material.

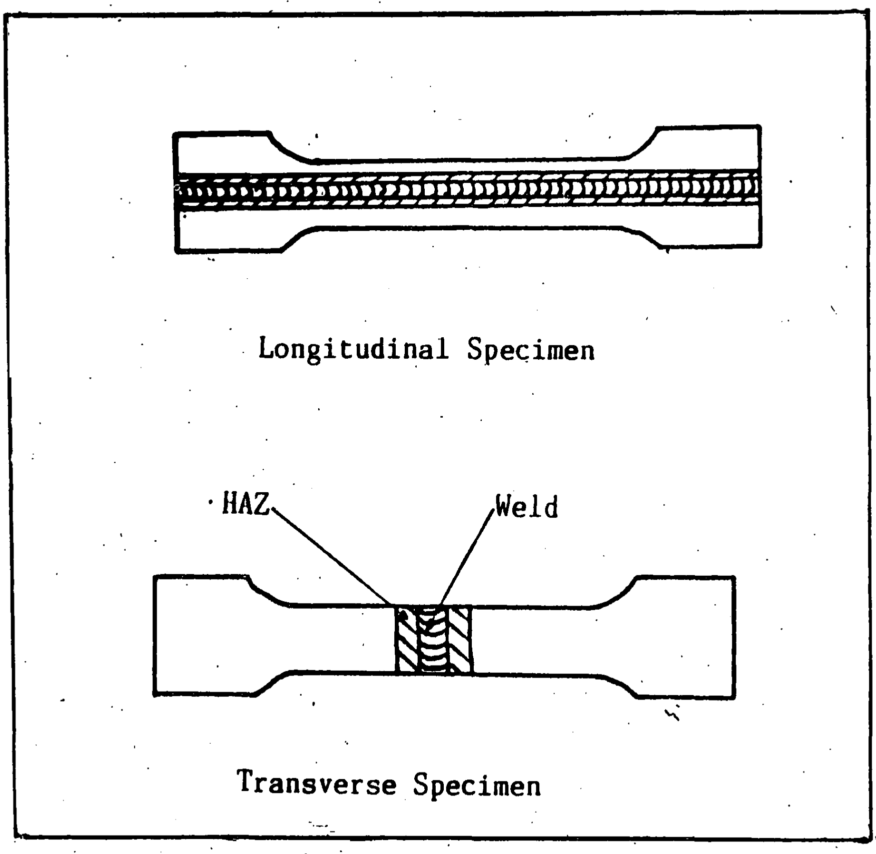

Fig. 2. Tensile Specimens for Weldment Testing