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Tom Magee

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BRITISH STANDARD

BS 3451:1973

Incorporating Amendment Nos. 1, 2, 3 and 4

Methods of testing

Fusion welds in aluminium and aluminium alloys

ICS 25.160.40

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Co-operating organizations

The Welding Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

Aluminium Federation*
Associated Offices Technical Committee*
Association of Consulting Engineers
British Constructional Steelwork Association*
British Railways Board
British Steel Industry*
Crown Agents for Oversea Governments and Administrations
Department of Employment*
Department of Trade and Industry*
Department of Trade and Industry — National Engineering Laboratory
Institution of Civil Engineers
Institution of Electrical Engineers
Institution of Mechanical Engineers*
Institution of Production Engineers
Institution of Structural Engineers*
Lloyd's Register of Shipping*
London Transport Executive*
Ministry of Defence
Ministry of Defence, Army Department*
Ministry of Defence, Navy Department*
Process Plant Association*
Shipbuilders' and Repairers' National Association*
Society of British Aerospace Companies Limited*
Welding Institute*
Welding Manufacturers Association*

The Government departments and scientific and industrial organizations marked with an asterisk in the above list, together with the following were directly represented on the committee entrusted with the preparation of this British Standard:

British Compressed Gases Association
British Non-ferrous Metals Research Association
Electricity Council, the Central Electricity Generating Board and the Area Boards in England and Wales
Engineering Employers Federation
National Physical Laboratory (Department of Trade and Industry)

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Foreword

The revision of this standard was undertaken to incorporate the developments in testing techniques that have occurred since the first edition was published in 1962 and to align the presentation of its contents with the style adopted for companion standards on the testing of welds in other materials.

Standards relating to welded construction in various branches of engineering generally include requirements for certain welding tests to be conducted. There is seldom any technical reason for divergence in the procedures followed for such welding tests and there are both practical and economic advantages to be gained in their standardization. The main purpose of this standard is to recommend test procedures and test specimens that should be quoted, or incorporated, in engineering application standards that deal with welded constructions of aluminium or aluminium alloy. Where differences exist between application standards, the methods of test given in this standard are to be preferred.

A general indication is given of the purpose served by each of the different tests, but the standard does not purport to lay down when any particular test should or should not be used; again it does not state the number of specimens to be tested, the repeat tests to be allowed in the event of failure or acceptance requirements. Such requirements are matters to be dealt with in the particular application standard, e.g. BS 5500, "Unfired fusion welded pressure vessels" and CP 118, "The structural use of aluminium", or are to be agreed between the contracting parties.

Tests for fusion welds in aluminium and aluminium alloys should be selected on their own merits, there being no value in making comparisons with other materials and experience in testing other materials is not necessarily valid. It should also be appreciated that variations in welding procedure and the quality of preparation of test specimens can give rise to variations in the test results.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 8, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1. General

1.1 Scope

This British Standard deals with methods for the testing of fusion welds in aluminium and aluminium alloys in all forms of material including pipes and castings.

Requirements for test plates, number of test specimens, mechanical test requirements and acceptance levels are not included. These are either covered in the appropriate application standard or to be agreed between the manufacturer and the purchaser.

NOTE The titles of the British Standards referred to in this standard are listed on the inside back cover.

1.2 Definitions

For the purposes of this British Standard, the definitions given in BS 499-1 apply.

1.3 Recommended non-destructive tests

The recommended non-destructive tests are:

1) visual examination aided by dye or fluorescent penetrant methods;

2) radiography.

NOTE Although no British Standard exists for the method, ultrasonic examination is sometimes applicable to aluminium and aluminium alloy welds. Under optimum conditions it can detect defects such as lack of fusion which are not always revealed by radiography, but interpretation can be complicated by the effect of the metallurgical structure. It is useful where radiography is not sufficiently sensitive because of thickness or joint configuration.

1.4 Recommended destructive tests

The recommended destructive tests are:

Butt welds

1) Transverse tensile test

2) Macroscopic examination

3) Side bend test

4) Transverse and longitudinal bend tests (under certain circumstances)

5) Fracture test (under certain circumstances)

Fillet welds

1) Macroscopic examination

2) Fracture test (under certain circumstances)

2. Non-destructive tests

2.1 Visual examination

2.1.1 Object. The object of visual examination is to check the contour and soundness of the surface of the weld zone. The use of penetrant methods (see BS 4416) is an aid to detecting flaws that would not be apparent under normal vision.

Visual examination is the primary method of weld examination and should always precede any other non-destructive or destructive testing.

2.1.2 Preparation. The weld shall be examined in the as-welded condition except that the surface to be examined shall be clean and free from any residues from the welding process.

2.1.3 Examination. The surface of the weld zone shall be examined visually with or without the use of a low power magnifier.

As a further aid to visual examination, one of the following types of penetrant methods (see BS 4416) may be used:

1) a coloured dye which indicates flaws after treating the weld with developer;

2) a fluorescent penetrant which reveals its presence under a beam of ultraviolet radiation; treatment with a developer may or may not be used. This is less suitable than 1) for site inspection and requires particularly careful interpretation.

All residues from penetrant testing shall be removed to avoid contamination when further welding or repair welding is required.

2.1.4 Reporting of results. The appearance and contour of the weld zone shall be described in the report, together with the nature and location of all flaws found. The use of any aid to examination shall be indicated in the report.

2.2 Radiographic examination

2.2.1 Object. The object of radiographic examination is to detect flaws which are not apparent during visual examination. It is useful for detecting "volume" defects such as porosity, cavities and tungsten or flux inclusions. It cannot always be relied upon to detect narrow planar defects such as cracks, oxide films, lack of fusion and incomplete root penetration.

2.2.2 Preparation. The surfaces of welded joints which are to be radiographically examined need not be chipped or ground to a smooth surface so long as the contours of the welds do not interfere with the interpretation of the radiograph.

Welded joints with backing material may be radiographed without removing the backing provided that the image of the latter is not significantly detrimental to the interpretation of the radiographs.

2.2.3 Weld image location. Markers, usually in the form of lead arrows or other symbols, shall be placed alongside but clear of the outer edges of the weld to identify its position.

2.2.4 Identification of radiographs. Each section of weld radiographed shall have suitable symbols affixed to identify:

1) the job or work-piece;

2) the joint;

3) the section of the joint.

The symbols, consisting of lead letters or numerals, shall be positioned so that their images appear in the radiograph to ensure unequivocal identification of the section.

2.2.5 Marking. In general, permanent marking of the work-piece shall be used to provide reference points for the accurate re-location of the position of each radiograph. Where the nature of the material and its service conditions render stamping undesirable, other suitable means of marking shall be used.

2.2.6 Radiographic technique

2.2.6.1 *General.* For the basic requirements relating to the radiographic examination of welds reference should be made to BS 2600-1 or BS 2910. Gamma-radiography is not recommended for aluminium alloys.

2.2.6.2 *Type of film.* The film shall be one of the following direct types:

ultra-fine-grain
fine-grain
medium speed } see BS 2600-1 or BS 2910

2.2.6.3 *Intensifying screens.* Lead screens shall not be employed for tube voltages less than 90 kV. For tube voltages in the range 90 kV to 120 kV lead screens 0.05 mm thick may be used.

For tube voltages over 120 kV front lead screens 0.1 mm thick and back lead screens 0.16 mm thick shall be used.

2.2.6.4 *Image quality indicators.* A wire-type image quality indicator (I.Q.I.) complying with the requirements specified in BS 3971 shall be placed at one end of every radiograph on the surface facing the source of radiation. It shall be positioned across the weld with the finest wire in the outermost position. The I.Q.I. sensitivity of the radiographic technique should be in accordance with the recommendations of BS 3971.

2.2.6.5 *Density of radiographs.* The photographic density of the radiographs shall be within the range 2.0 to 3.0 at the weld area under examination.

2.2.6.6 *Tube voltage.* The tube voltage for pulsating X-ray generation circuits shall not exceed the value obtained from Figure 1, and shall be chosen so that the exposure is not less than 8 milliampere-minutes for techniques employing the medium-speed film, or 15 milliampere-minutes for techniques employing fine-grain or ultra-fine-grain films. For constant potential circuits, the tube voltage shall not exceed 90 % of the value obtained from Figure 1.

2.2.7 Reporting of results. The following information shall be reported as results of the examination.

1) Identification markings.

2) A description of the joint design, material thickness and welding process employed.

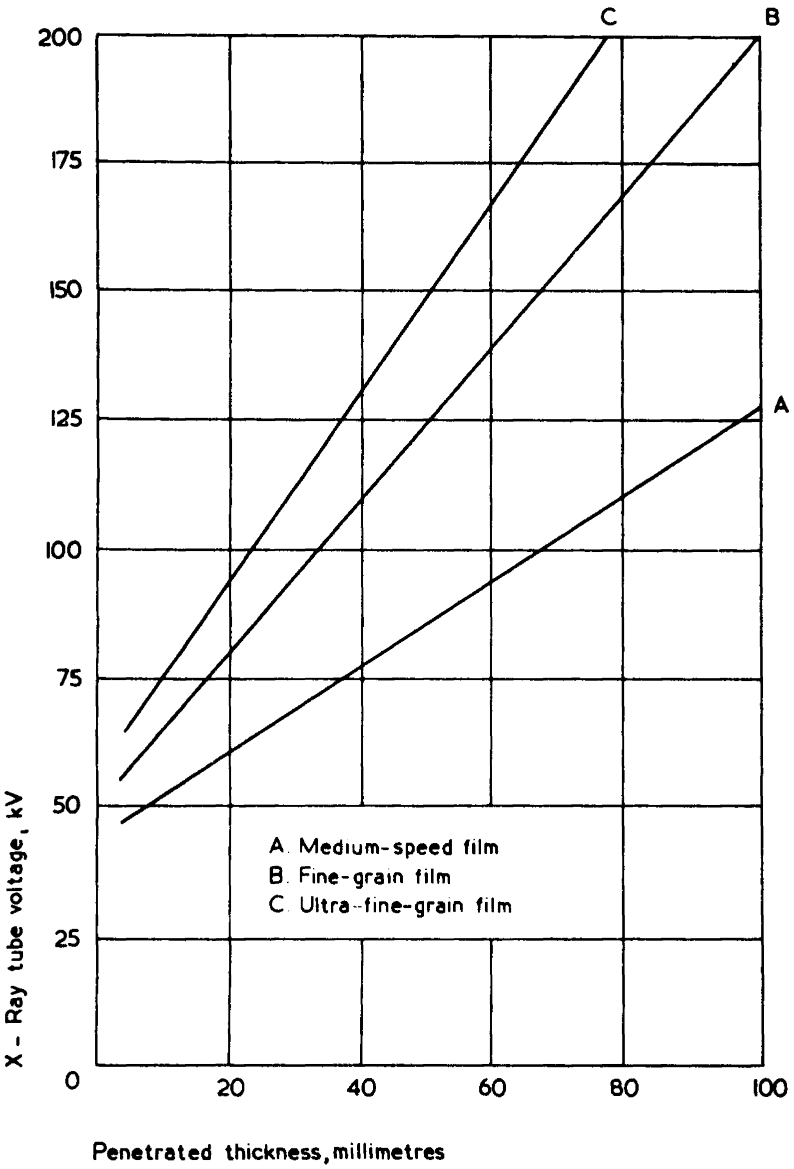
3) I.Q.I. type and sensitivity achieved.

4) A sketch showing the geometry of image formation i.e. direction of radiation in relation to joint geometry and position of film.

5) Interpretation of the radiograph. A note should be made of any processing or film defects (artefacts). Surface marks caused by processes other than welding and defects in the parent metal should be reported separately from weld defects. In cases where the relevant weldment is available a companion report on the results of visual examination should accompany the radiographic report.

Abbreviations for weld defects, if used, should be in accordance with BS 499-3.

6) Details of the radiographic technique including equipment used, focal spot size, film type, screens (if any), focus-to-film distance, film density (weld and parent metal), tube voltage, current, exposure time and processing conditions shall be recorded and reported if required.



NOTE The thickness in question is the total thickness penetrated. This may include a backing ring, excess weld metal, and, in the case of double wall methods, an additional wall thickness. The radiographic sensitivity should be calculated with respect to this total thickness penetrated. It should be recognised, however, that the sensitivity of flaw detection is impaired by superimposed metal thickness.

Figure 1 — Maximum X-ray tube voltage (see also 2.2.6.6)

3. Destructive tests

3.1 Separation of test specimens

The best method for separating test specimens from the test piece is usually by mechanical cutting, but when a specimen is sheared or thermally cut an adequate allowance shall be left for further machining. Any angular misalignment of welded test pieces shall be corrected cold before mechanical cutting, unless metallurgical conditions make this undesirable (see Appendix A). To avoid localization of stress and premature failure, tool marks shall be minimized and shall preferably run parallel to the length of the specimens.

3.2 Transverse tensile test

Transverse tensile tests shall be in accordance with BS EN 895.

Table 1 — *Table deleted*

Figure 2 — *Figure deleted*

Figure 3 — *Figure deleted*

Figure 4 — *Figure deleted*

Table 2 — *Table deleted*

Table 3 — *Table deleted*

Figure 5 — *Figure deleted*

Figure 6 — *Figure deleted*

3.3 Macroscopic examination

Macroscopic examination shall be in accordance with BS EN 1321

Figure 7 — *Figure deleted*

3.4 Side bend test (for material of thickness 10 mm and over)

Side bend tests (for material of thickness 10 mm and over) shall be carried out in accordance with BS EN 910:1996.

Figure 8 — *Figure deleted*

Figure 9 — *Figure deleted*

3.5 Transverse and longitudinal bend tests

Transverse and longitudinal bend tests shall be carried out in accordance with BS EN 910:1996.

Figure 10 — *Figure deleted*

Figure 11 — *Figure deleted*

3.6 Fracture test (for material of thickness 2 mm and over)

Fracture tests shall be in accordance with BS EN 1320.

Figure 12 — *Figure deleted*

3.7 Fillet weld fracture test (for material of thickness 3 mm and over)

3.7.1 Object. The fracture test on fillet welded joints is intended to reveal the depth of penetration and the presence of root defects.

3.7.2 Preparation of test specimen. The test specimen shall be prepared according to one of the forms shown in Figure 13. To ensure fracture in the weld a central saw cut 1.5 mm deep may be made along the length of the weld face. With high ductility materials it may be necessary to increase the depth of the saw cut.

3.7.3 Testing. The specimens shall be fractured by bending or by blows applied in the direction indicated in Figure 13.

3.7.4 Reporting of results. The following information shall be reported as results of the test.

1) Thickness of parent metal.

2) Throat thickness and leg length of weld.

3) Location of fracture.

4) Appearance of joint after testing, e.g. type and location of any flaws present.

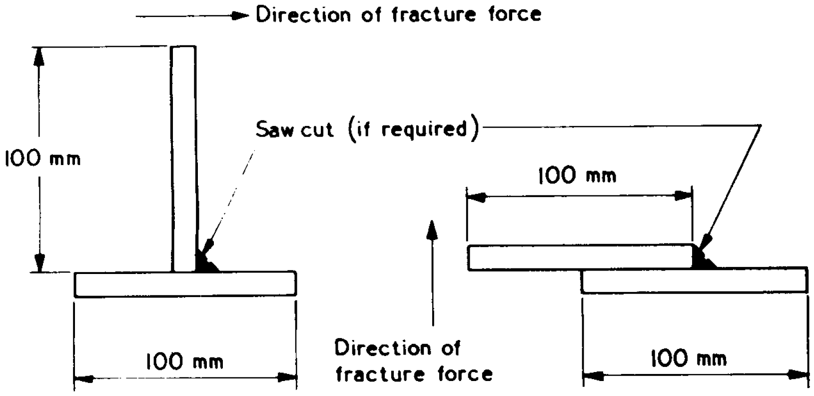


Figure 13 — Alternative forms of fillet weld fracture test specimen

Appendix A Metallurgical aspects of testing welds in aluminium

A.1 Non-heat-treatable alloys

Pure aluminium and a number of its alloys are termed non-heat-treatable because they can be hardened only by cold working. The application of heat, as in fusion welding, causes little change to the structure and mechanical properties of such materials when they are in the annealed condition, but work-hardened metal is softened adjacent to the weld. Some forms of these wrought materials, such as plate and extrusions, are supplied in the "as manufactured" condition. Generally they will be work-hardened to a slight extent and therefore will be softened locally by the heat of the welding process. Figure 14 illustrates the different zones in such a welded joint and indicates the pattern of the variation in hardness which may be expected.

Welded joints in pure aluminium and the non-heat-treatable alloys are generally made with filler metal of the same nominal composition as the components to be welded or without the addition of filler metal, and because of the structural difference between cast and wrought metal, the strength and ductility of the weld metal are usually slightly less than those of the annealed wrought components. In the case of alloys 5251 and 5154A (see BS 1470 – BS 1475), a filler material of higher magnesium content is usually employed in order to minimize the risk of weld cracking during solidification and in such instances the weld metal can be stronger than the annealed parent material.

Associated with the differences in structure and possibly composition which may exist across fusion welded joints in these materials, there are differences in the mechanical properties. The values obtained for conventional proof stress and percentage elongation will be rather variable, being determined by the width of the softened region (i.e. by the welding conditions) as well as by the initial temper. Because of the heterogeneous nature of the joint it should be appreciated that proof stress determination and elongation measurements cannot easily be compared with other welds in different thicknesses and alloys. Elongation measurements should always be quoted as a percentage of a specified gauge length. Elongation values should be considered in relation to both tensile strength and location of fracture. Low elongation, coupled with weld metal failure, does not usually mean brittle weld metal. It is more likely to indicate low strength weld metal or the presence of defects. Generally, the elongation value rises with an increase in tensile strength of the joint. The parallel portion of a tensile test piece should be sufficiently long to include the heat-affected zone. Generally, a parallel length six times the width of the weld is sufficient for this purpose. Variations in the width of the softened region will also affect bend tests on butt welds, particularly those made with the axis of the bend parallel to the direction of the weld. When a weld in work-hardened material is subjected to a bend test, this should be of the controlled type to ensure that the specimen conforms to the mandrel otherwise "peaking" will occur and the strain will be concentrated in the weakest point (which will be either the weld or heat-affected zone) to such an extent that premature failure may occur. It is for this reason that the free bend test is not recommended. A joint of similar quality in annealed material of the same composition would bend satisfactorily because the strain would be more uniformly distributed between the weld metal or heat-affected zone and the surrounding material.

When sound joints in annealed pure aluminium or non-heat-treatable alloys welded with filler metal of the same nominal composition are tested in tension with excess weld metal left on, the point of failure will be either at the edge of the weld or at some distance remote from the weld. When the excess weld metal is removed, failure is most likely to occur within the weld metal. In the case of sound welds in work-hardened material, failure will occur at the edge of the weld when the excess weld metal is left on and in the weld metal when the excess weld metal is removed.

A.2 Heat-treatable alloys

A number of aluminium alloys are described as "heat-treatable" because, although they can be hardened somewhat by cold working, they are normally and more effectively hardened by heating to a temperature in the range 450 °C to 540 °C depending upon composition, quenching and then ageing either at room temperature or at a temperature usually in the range 100 °C to 200 °C. Fusion welded joints in these materials are often made with filler metal of significantly different composition in order to achieve freedom from weld cracking (and to ensure adequate strength), although they are occasionally made without the addition of filler metal.

In most cases, the weld metal age hardens on standing and thus becomes stronger than the over-aged material in the heat-affected zones as shown in Figure 15. Hence, when joints in these materials are tested in tension in the "as welded" condition with the excess weld metal left on, failure usually occurs some distance away from the weld; with sound weld metal this may also occur when the excess weld metal is removed. However, the precise position of the failure, the proof stress, the tensile strength and the ductility of the joint will, for a given alloy, depend upon the extent of the softening produced, which is governed principally by the welding conditions and the thickness of the material. When "as welded" joints in heat-treatable alloys are subjected to bend tests which permit "peaking", bending will be concentrated in the softened regions of the heat-affected zones. The strength of joints in the heat-treatable alloys may largely be recovered by complete re-heat-treatment after welding, but the ductility of the weld metal will be somewhat less than that of the wrought material remote from the weld. It should be noted that it is particularly important to keep angular and linear misalignment to a minimum when tensile testing welds in heat-treatable alloys to prevent non-uniform loading.

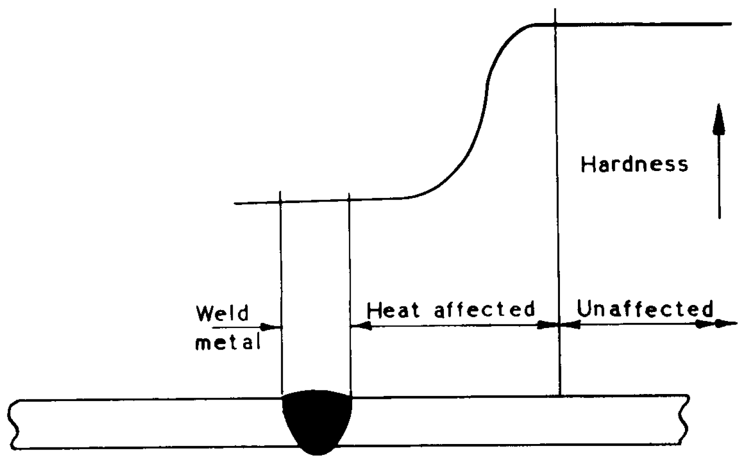


Figure 14 — Weld zones in non-heat-treatable alloys

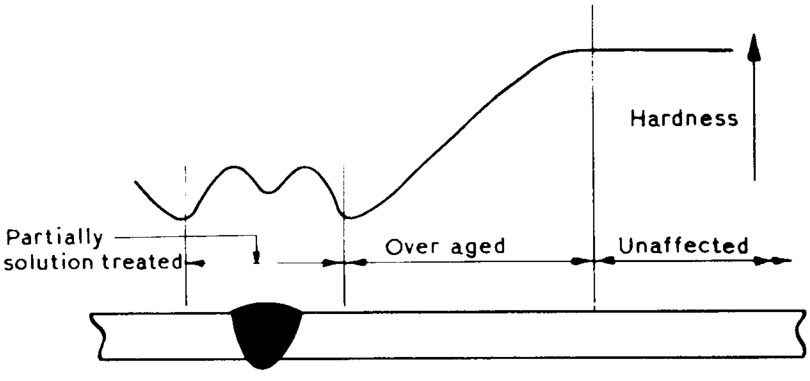


Figure 15 — Weld zones in heat-treatable alloys

Appendix B Suggested method of preparing etched specimens

B.1 Preparation of surfaces for etching

The initial preparation of a cut surface may be by milling or turning. Alternatively, the surface should be filed with a coarse file until all deep marks are removed. It should then be filed at right angles to the original coarse file marks with a smooth file. The application of chalk to the teeth of the fine file will reduce the risk of surface scoring by metallic particles trapped in the teeth of the file.

The machined or smooth-filed surface is then abraded on successively finer grades of waterproof silicon carbide paper (see BS 872). A suitable sequence of grit sizes is 100, 240, 400 and 600. If the specimen is of suitable size to be conveniently handled, the most satisfactory procedure is to lay the appropriate sheet of abrasive paper, face up, on a flat surface such as plate glass, resin impregnated paper laminate, etc. The abrasive paper is then lubricated either with water, industrial alcohol, or white spirit, and the specimen carefully rubbed on it, with the application of moderate pressure, until all traces of the surface scratching from the previous treatment are removed. The specimen is then washed to remove all traces of abrasive, and the procedure repeated with the next finer grade of abrasive paper, the direction of abrading in each case being at right angles to the marks made by the previous paper.

In cases where the specimen size is such that the above procedure is inconvenient, the abrading may be carried out by employing rotating abrasive disks in a suitable hand tool. This operation will of necessity be carried out dry, and successively finer grit sizes should be used, as in the wet method. Care should be taken to avoid exerting undue pressure on the surface, since this will cause metal to flow over and obscure any fine porosity which may by present.

A fine-machined surface, produced by sharp tools, with adequate lubrication, is suitable for macro-etching without any further preparation, and the abrading of a filed surface need only be taken as far as 400 grade for a satisfactory etch to be obtained. Such machined surfaces are not, however, in the most suitable condition for the detection of fine porosity, for which purpose it is recommended that abrading down to 600 grade paper should be employed.

B.2 Etching for macro-examination

Suitable etchants for welds in pure aluminium and all wrought alloys are the following:

1) 45 % by volume of hydrochloric acid (d = 1.16)
   15 % by volume of nitric acid (d = 1.42)
   15 % by volume of hydrofluoric acid (40 % m/m HF)
   25 % by volume of water

2) Sodium hydroxide (100 g/l) for 10 s to 20 s, less if warmed, followed by cleaning in nitric acid (d = 1.42)

NOTE Care should be exercised in handling these etchants. In particular hydrofluoric acid, even when very dilute, must not come into contact with fingernails.

Etching is carried out either by swabbing with cotton wool or by immersion. After this treatment the specimen should be washed in water, the surface blotted with filter paper and dried in warm air.

Publications referred to

This standard makes reference to the following British Standards:

BS 499, *Welding terms and symbols.*

BS 499-1, *Welding, brazing and thermal cutting glossary.*

BS 499-3, *Terminology of and abbreviations for fusion weld imperfections as revealed by radiography.*

BS 872, *Abrasive papers and cloths (technical products).*

BS 1470 – BS 1475, *Wrought aluminium and aluminium alloys for general engineering purposes.*

BS 2600, *Methods for the radiographic examination of fusion welded butt joints in steel.*

BS 2600-1, *5 mm up to and including 50 mm thick.*

BS 2901, *Filler rods and wires for gas-shielded arc welding.*

BS 2901-4, *Aluminium and aluminium alloys and magnesium alloys.*

BS 2910, *Methods for the radiographic examination of fusion welded circumferential butt joints in steel pipes.*

BS 3971, *Image quality indicators for radiography and recommendations for their use.*

BS 4416, *Method for penetrant testing of welded or brazed joints in metals.*

BS EN 895, *Destructive tests on welds in metallic materials — Transverse tensile test.*

BS EN 910, *Destructive tests on welds in metallic materials — Bend test.*

BS EN 1320, *Destructive tests on welds in metallic materials — Fracture test.*

BS EN 1321, *Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds.*

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