

Specification for

Arc welding of carbon and carbon manganese steels

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- Engineering Equipment and Materials Users' Association
- Institution of Mechanical Engineers
- Institution of Structural Engineers
- Ministry of Defence
- National Coal Board
- Process Plant Association
- Water-tube Boilermakers' Association
- Welding Institute
- Welding Manufacturers' Association
- Associated Offices Technical Committee
- British Constructional Steelwork Association
- British Railways Board
- British Shipbuilders
- British Steel Industry
- Electricity Supply Industry in England and Wales

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Foreword

This revision of this British Standard has been prepared under the direction of the Welding Standards Committee. It is the first revision of this standard since the original 1974 edition which is withdrawn.

Because of its range of applicability, it has been used extensively over a wide field of types of fabrication and has received due recognition as a comprehensive welding standard. Experience gained in its use has been reflected in the changes incorporated in this revision, principally by converting most of the previous guidance on the avoidance of hydrogen cracking into requirements which have to be followed whenever practicable. Appendices giving recommendations concerning various modes of cracking and factors to be taken into account in establishing welding procedures have been retained in updated form.

Permissible stresses in welds, methods of testing and acceptance levels are not specified because they depend on the service conditions of the fabrication. These requirements should be obtained from the relevant application standard or by agreement between the contracting parties. An appendix has been introduced giving guidance on four levels of acceptance criteria which may be used to assist in reaching agreement.

It has been assumed in the drafting of this standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 50, 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 Scope

This British Standard specifies requirements for manual, semi-automatic, automatic and mechanized arc welding of carbon and carbon manganese steel of maximum carbon equivalent of 0.54 (see clause 4) in all product forms including circular and rectangular hollow sections.

In addition to the definitive requirements, it also requires the items detailed in clause 3 to be documented. For compliance with this standard, both the definitive requirements and the documented items have to be satisfied.

The requirements given in clause 21 are appropriate only to normal fabrication restraint conditions and higher restraint situations need higher preheat or other precautions to prevent hydrogen cracking. Some guidance on this is given in Appendix E.

The appendices are intended to assist users of this standard by giving guidance on various topics, but adherence to what is stated in the appendices does not form part of compliance with this standard.

This standard does not include all the requirements for the welding of steel for concrete reinforcement which may be affected by other factors not covered by this standard.

This standard does not cover requirements for cast to cast fabrications which are specified in BS 4570.

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

2 Definitions

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

3 Information and requirements to be agreed and to be documented

3.1 Information to be supplied by the purchaser. The following information to be supplied by the purchaser shall be fully documented. Both the definitive requirements specified throughout the standard and the documented items shall be satisfied before a claim of compliance with the standard can be made and verified.

- The application standard to be used together with any supplementary requirements.
- Specification of the parent metal and of the required weld metal and welded joint properties.
- Locations, dimensions and details, i.e. form of joint, angle between fusion faces, gaps between parts, etc. of all welds.

NOTE When symbols are used for standard weld forms, they should conform to BS 499-2.

d) Whether the welds are to be made in the shop or elsewhere.

e) Whether written welding procedures are required (see clause 20).

f) Whether welding procedure approval testing is required (see clause 22).

g) Whether means of identification to enable welds to be traced to the welder who made them is required and if so the methods to be used (see clause 24).

h) Surface finish of weld profile.

i) Quality control arrangements.

j) Whether post-weld heat treatment is required (see clause 29).

NOTE The items referred to in this clause may have a significant effect upon the performance of the fabrication and the purchaser should ensure that the requirements relate appropriately to the particular joints and intended service life of the fabrication.

3.2 Requirements to be agreed. The following items to be agreed between the contracting parties, which are specified in the clauses referred to, shall be fully documented.

Both the definitive requirements specified throughout the standard and the following documented items shall be satisfied before a claim of compliance with the standard can be made and verified.

- When no dressing is to be carried out, the permissible weld profile if it is not specified in the application standard (see 7.3.2).
- The use of a special method to achieve full penetration without the use of backing material when a butt weld is to be welded from one side only (see 7.4 b) 2)).
- The material for backing when this is not part of the structure (see 7.5.2).
- Methods other than those specified in 10.1 for preparation or cutting of material (see 10.2).
- The peening of welds (see clause 25).
- The method and extent of inspection and testing in the absence of a relevant application standard (see 26.2).
- The acceptance requirements for welded joints in the absence of a relevant application standard (see 27.2).
- When post-weld heat treatment is required but there is no application standard, the details of the heat treatment to be applied (see 29.2).

4 Parent metal

The parent metal shall be a carbon or carbon manganese steel whose chemical composition, in % (*m/m*), determined by ladle analysis provides a maximum carbon equivalent of 0.54 when calculated using the following formula:

$$\text{Carbon equivalent} = C + \frac{\text{Mn}}{6} + \frac{\text{Cr} + \text{Mo} + \text{V}}{5} + \frac{\text{Ni} + \text{Cu}}{15}$$

NOTE 1 This carbon equivalent formula may not apply to carbon manganese steels of low carbon content or boron containing steels and therefore the guidance given in E.3 should be followed.

NOTE 2 Requirements are not specified for carbon manganese steels above a carbon equivalent of 0.54 because fabrication experience is limited. The steelmaker, welding consumable supplier or other appropriate authoritative source should be consulted with regard to the welding procedures for these steels.

5 Welding consumables

5.1 Hydrogen levels. When hydrogen-controlled welding consumables are to be used, the contractor shall be able to demonstrate that he has used the consumables in the manner recommended by the consumable manufacturer and that the consumables have been dried or baked to the appropriate temperature levels and times.

5.2 Manual metal-arc welding. Electrodes shall be selected having regard to the particular application, i.e. joint design, welding position and the properties required to meet service conditions (see 3.1 b)). Where there is a British Standard applicable to the electrodes selected, they shall comply with and be coded in accordance with that standard (e.g. BS 639).

5.3 Covered electrodes for semi-automatic, automatic and mechanized metal-arc welding. The weld metal produced from covered electrodes used with semi-automatic, automatic and mechanized metal-arc welding processes¹⁾ shall have mechanical properties not less than the minimum specified for the weld metal produced by electrodes complying with BS 639 having regard to the particular application, i.e. joint design, welding position and the properties required to meet service conditions (see 3.1 b)).

5.4 Submerged arc welding. Electrode wire and flux combinations for submerged arc welding shall comply with the appropriate sections of BS 4165. The combination shall be selected having regard to the particular application, i.e. joint design, welding position and the properties required to meet service conditions (see 3.1 b)).

5.5 Gas-shielded processes

5.5.1 Filler rods and wires. Where a solid metal filler rod or wire is used with a gas-shielded process, it shall comply with BS 2901-1 and shall be selected having regard to the particular application, i.e. joint design, welding position and the properties required to meet service conditions (see 3.1 b)).

Cored electrodes, when used with the appropriate shielding gas or gas mixture, shall be selected having regard to the particular application, i.e. joint design, welding position and the properties required to meet service conditions (see 3.1 b)).

5.5.2 Shielding gases. When a gas or gas mixture is used, it shall be of the following quality, as appropriate:

- argon complying with BS 4365;
- carbon dioxide complying with type 1 specified in BS 4105;
- gas mixtures that have been proved to be satisfactory as a result of either experience or procedure approval tests.

5.6 Unshielded semi-automatic arc welding.

Electrodes for unshielded semi-automatic arc welding, which are usually of the cored type, shall be selected having regard to the particular application, i.e. joint design, welding position and the properties required to meet service conditions (see 3.1 b)).

5.7 Storage and handling

5.7.1 General. All consumables shall be stored and handled with care and in accordance with the manufacturer's recommendations. Electrodes, filler wires and rods and fluxes that show signs of damage or deterioration shall not be used.

NOTE Examples of damage or deterioration include cracked or flaked coatings on covered electrodes, rusty or dirty electrode wires and wires with flaked or damaged copper coatings.

5.7.2 Covered electrodes. Electrodes shall be stored in their original containers in a dry, preferably heated place adequately protected from the effects of the weather and in accordance with the manufacturer's recommendations. When special protection or other treatment during storage or immediately prior to use is recommended by the electrode manufacturer, they shall be treated in accordance with the conditions detailed by the manufacturer.

In order to ensure that the weld metal deposited by hydrogen-controlled electrodes falls within the limits of the appropriate scale as specified in clause 21, the drying or baking conditions indicated by the electrode manufacturer shall be followed.

¹⁾ This group of processes embraces gravity and auto-contact welding with long straight lengths of covered electrode and open arc welding with a continuous covered electrode.

Electrodes shall be removed from their original containers before drying or baking. After removal from the oven, the electrodes shall be protected from exposure to conditions conducive to moisture absorption.

NOTE 1 If the lowest hydrogen levels are required, it may be necessary for welders to be issued with electrodes in quivers or sealed containers.

Electrodes returned to stores shall be treated in accordance with the electrode manufacturer's recommendations before re-issue.

NOTE 2 If electrodes have been exposed to poor storage conditions or it is suspected that they have become damp, the advice of the manufacturer should be sought before use.

5.7.3 Semi-automatic, automatic and mechanized welding. Wire or cored electrodes shall be suitably packed to guard against damage, including that during transportation. When stored, the wire or electrode shall be kept in its original bundle or package in a dry storeroom.

NOTE The performance of copper coated wires depends on the continuity and regularity of the copper coating. This is often not apparent on visual inspection but may be important in critical applications. Such considerations should be agreed between the contractor and the supplier.

Flux shall be packed in such a way that it is protected from moisture pick-up and damage, including that during transportation. Flux with a guaranteed moisture level or giving a controlled hydrogen level as deposited shall be packed in moisture-resistant containers. When stored, the flux shall be kept in its original container in a dry storeroom.

If the composition of the flux is such that special protection during storage or special treatment before use is desirable, details of such special protection or treatment shall be provided by the manufacturer and implemented by the contractor.

6 Equipment

6.1 Plant. Welding plant, instruments, cables and accessories shall comply with the requirements of the appropriate Parts of BS 638. The contractor shall be responsible for ensuring that the capacity of the welding plant and ancillary equipment is adequate for the welding procedure to be used and for maintaining all welding plant and ancillary equipment in good working order.

NOTE The attention of the contractor is drawn to the advice on safety precautions contained in the Health and Safety at Work booklet no. 38 "Electric arc welding" issued by the Health and Safety Executive and published by HM Stationery Office.

6.2 Earthing. All electrical plant in connection with the welding operation shall be adequately earthed. The welding return lead from the work shall be adequate in cross section and shall be correctly connected and earthed.

6.3 Instrumentation. Means of measuring the current shall be available, either as part of the welding plant, or by the provision of a portable ammeter.

In the cases of semi-automatic, automatic and mechanized welding, means shall be provided for measuring the arc voltage, current and/or wire feed speed.

Drying ovens shall be provided with means of measuring the oven temperature.

7 Butt weld details

7.1 General. The details of all butt welds, e.g. form of joint, angle between fusion faces, gap between parts, shall be arranged to permit the use of a satisfactory welding procedure and the combination of weld detail and welding procedure shall be such that the resultant joint will comply with the requirements of the design.

NOTE 1 Guidance on design of butt welds is given in A.1, Appendix B and Table 16.

NOTE 2 Incomplete penetration butt welds intentionally have a throat thickness that is less than the parent metal thickness. This type of weld is acceptable in many circumstances, but for restrictions on its use, see A.1.

7.2 Throat thickness. The ends of butt joints in plate shall be welded so as to provide the full throat thickness.

NOTE This may be done by the use of extension pieces or other means approved by the purchaser.

7.3 Weld profile

7.3.1 In the as-welded condition, the weld face shall be proud of the surface of the parent metal. Where a flush surface is required, the excess weld metal shall be dressed off. When no dressing is to be carried out, the weld profile shall be as specified in the application standard where it exists.

7.3.2 When no dressing is to be carried out and no application standard exists, the weld profile shall be agreed between the contracting parties.

7.4 Full penetration. Full penetration single, V, U, J, bevel or square butt welds shall be completed as described in either a) or b):

- a) by depositing a sealing run of weld metal on the back of the joint,
 - b) where these or other butt welds are to be welded from one side only,
- either

- 1) with the aid of temporary or permanent backing material, or
- 2) by agreement between the contracting parties, by the adoption of an approved special method of welding that gives full penetration without the use of either type of backing material.

NOTE Under fatigue conditions, permanent backing material may be undesirable.

7.5 Backing material

7.5.1 Backing material shall consist of another steel part of the structure when this is appropriate.

7.5.2 When it is not appropriate to use part of the structure as backing material, the material to be used shall be agreed between the contracting parties.

NOTE Care should be taken when using copper as a backing material as there is a risk of copper pick-up in the weld metal.

7.5.3 Where temporary or permanent backing material is employed, the joint shall be arranged in such a way as to ensure that complete fusion of the parts to be joined is readily obtained.

7.6 Back gouging. In all full penetration butt welds, where these are to be welded from both sides, certain welding procedures allow this to be done without back gouging, but where complete penetration cannot be achieved, the back of the first run shall be gouged out by suitable means to clean sound metal before welding is started on the gouged-out side (see Figure 1).

8 Fillet weld details

A fillet weld, as deposited, shall be not less than the specified dimensions (see 3.1 c)) which shall be clearly indicated as throat thickness and/or leg length as appropriate, taking into account the use of deep penetration processes or partial preparations (see clause 14 and, for guidance, Appendix C).

For concave fillet welds, the actual throat thickness shall be not less than 0.7 times the specified leg length (see 3.1 c)). For convex fillet welds, the actual throat thickness shall be not more than 0.9 times the actual leg length.

Where the specified leg length (see 3.1 c)) of a fillet weld at the edge of a plate or section is such that the parent metal does not project beyond the weld, melting of the outer corner or corners, which reduces the throat thickness, shall not be allowed (see Figure 2).

NOTE Guidance on the design of fillet welds is given in A.2.

9 Welds in slots

Because of the risk of cracking, slots shall not be filled with weld metal unless required by the application standard. Slots that are required to be filled with weld metal shall only be filled after the fillet weld has been inspected and approved.

10 Preparation of joint faces

10.1 If preparation or cutting of the material is necessary, this shall be done by shearing, chipping, grinding, machining, thermal cutting, thermal gouging or an alternative method agreed in accordance with 10.2. When shearing is used, the effect of work hardening shall be taken into account and precautions shall be taken to ensure that there is no cracking of the edges.

In the cases where the cut edge is not a fusion face, the effect of embrittlement from shearing, thermal cutting or thermal gouging shall not be to the detriment of the performance of the fabrication.

NOTE Local hardening can be reduced by suitable thermal treatment or removed by mechanical means. The removal of 1 mm to 2 mm from a cut face normally eliminates the layer of hardness. When using thermal cutting, local hardening can be reduced by a reduction in normal cutting speed or by preheating before cutting. The steel supplier should be consulted for recommendations on achieving a reduction in hardness.

10.2 Methods for preparation or cutting of the material other than by shearing, chipping, grinding, machining, thermal cutting or thermal gouging (as referred to in 10.1) shall only be used by agreement between the contracting parties.

11 Fusion faces

11.1 The preparation of fusion faces, angle of bevel, root radius and root face shall be such that the limits of accuracy required by the appropriate application standard can be achieved.

NOTE When no appropriate application standard exists, it is recommended that, for manual welding, the tolerances on limits of gap and root face should be ± 1 mm on the specified dimensions (see 3.1 c)) for material up to and including 12 mm thick and ± 2 mm for material over 12 mm thick. The tolerance on the included angle between the fusion faces of a V preparation is recommended to be $\pm 5^\circ$ and for U and J preparations $+10^\circ, -0^\circ$. For an automatic or mechanized process, closer limits are necessary which depend on the characteristics of the process.

11.2 Fusion faces and adjacent surfaces shall be free from cracks, notches or other irregularities which would interfere with the deposition of the weld or be the cause of defects. Any repair to fusion faces shall be carried out in accordance with the requirements of this standard.

11.3 Fusion faces and the surrounding surfaces shall be free from heavy scale, moisture, oil, paint or any other substance which might affect the quality of the weld or impede the progress of welding.

NOTE This is particularly important when a hydrogen-controlled welding process is used. Certain proprietary protective coatings are specially formulated with the intention that they should not interfere with welding. The use of such coatings is not excluded by the requirements of this clause but, if so required by the purchaser, the contractor should demonstrate their acceptability by means of specimen welds (see BS 6084).

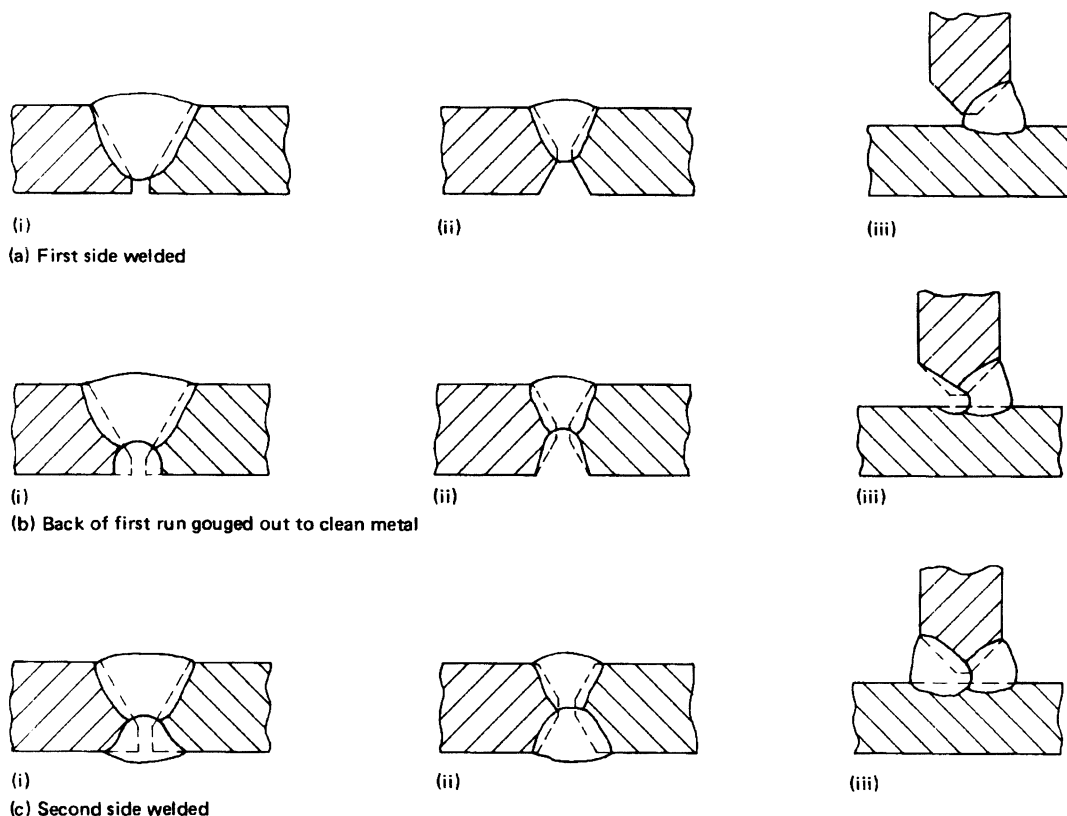


Figure 1 — Diagrammatic representation of method of gouging out full penetration butt joints welded from both sides

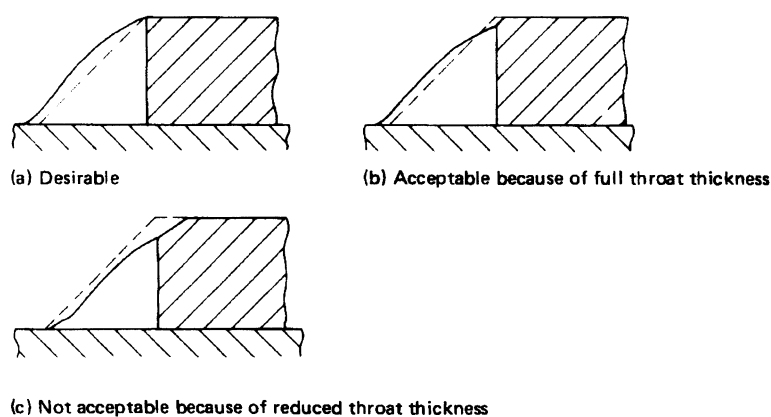


Figure 2 — Fillet welds applied to the edge of a part

12 Assembly for welding

Parts to be welded shall be assembled such that the joints to be welded are easily accessible and visible to the operator.

NOTE Jigs and manipulators should be used, where practicable, so that the welding can be carried out in the most suitable position.

13 Alignment of butt joints

The root edges or root faces of butt joints shall not be out of alignment by more than 25 % of the thickness of the thinner material for material up to and including 12 mm thick, or by more than 3 mm for material thicker than 12 mm.

NOTE For certain applications and welding processes, closer tolerances may be necessary.

14 Fit-up of parts joined by fillet welds

The edges and surfaces to be joined by fillet welds shall be in as close contact as possible since any gap increases the risk of cracking, but in no case shall the gap exceed 3 mm.

NOTE Consideration should be given to the need to increase the leg length of the fillet weld to compensate for a large gap (see clause 8 and, for guidance, Appendix E).

15 Tack welds

Tack welds shall be not less than the throat thickness or leg length of the root run to be used in the joint and shall be subject to the same welding conditions as those specified in this standard for the root run. The length of the tack weld shall not be less than four times the thickness of the thicker part or 50 mm whichever is the smaller.

Where a tack weld is incorporated in a welded joint, the shape of the tack shall be suitable for incorporation in the finished weld, and it shall be free from cracks and other deposition faults. Tack welds which crack shall be cut out (see clause 28).

In joints welded by an automatic or mechanized process or where smaller tack welds are desired, the conditions for deposition shall be as given in clause 21.

16 Temporary attachments

16.1 Welds for temporary attachments shall be made in accordance with the same requirements of this standard that apply to permanent welds.

NOTE Temporary attachments should be remote from principal joints as far as practicable.

16.2 When welded attachments used to facilitate construction are required to be removed, this shall be done carefully by cutting or chipping and the surface of the material shall always be finished smooth by grinding followed by surface crack detection. Temporary attachments shall not be removed by hammering.

17 Protection from the weather

Surfaces to be welded shall be dry. Whenever there is any evidence of condensation taking place on metal surfaces, warming shall be carried out to remove such condensation. In any case no welding shall be carried out on parent metal below 0 °C. When rain or snow is falling, or during periods of high wind, necessary precautions shall be taken to protect outdoor welding areas. Draughts shall be prevented from blowing along the bores of structural hollow sections when the bore will be penetrated during welding.

Where gas-shielded welding processes are being used, air currents at speeds as low as 8 km/h can remove the shielding gas, and therefore sufficient screening shall be used to keep winds and draughts away from the welding area.

18 Stray arcing on work

Precautions shall be taken to avoid stray arcing which can occur:

- a) between the electrode and the work away from the weld preparation;
- b) between the electrode holder and the work;
- c) between the work and the welding earth return lead connection;
- d) between the work and any part at earth potential;
- e) with semi-automatic, automatic and mechanized welding, between parts of the welding head or torch (e.g. loose contact tube in MIG gun) and the workpiece;
- f) with TIG welding, between the tungsten electrode and the work.

NOTE Local hard spots or cracking produced by stray arcing may need to be removed by mechanical means and be checked by inspection, after consultation between the contracting parties. Removed hard spots may be made good by the deposition of weld metal in accordance with this standard.

Items b), c) and e) can result in localized contamination with copper. The contaminated area may be brittle and/or cracked due to intergranular penetration of copper. These areas should be removed by mechanical means.

Items c) and d) can be avoided by a firm earth connection (see 6.2).

Item f) can give rise to tungsten inclusions in the workpiece. This contamination is not so serious as copper contamination but where the inclusions are large and angular or numerous they should be removed by mechanical means.

19 Inter-run cleaning

Where a process generates a slag to protect the weld metal, e.g. manual metal-arc and submerged arc welding, this slag shall be removed from each run of weld metal before a further run is superimposed, particular attention being paid to the junctions between the weld metal and the fusion faces. Visible defects such as cracks, cavities and other deposition faults shall be removed before the deposition of further weld metal.

20 Details of welding procedure

When written welding procedures are required by the purchaser, they shall include such of the following items as are relevant.

- a) Welding process or processes when more than one is used in making a complete joint.
- b) Parent metal specification, thickness and other relevant dimensions.
- c) Whether shop or site welding.
- d) Cleaning, degreasing, etc.
- e) Classification, type and size of electrodes and other consumables.
- f) For manual welding, the size of electrode, welding current and length of run per electrode or fillet weld leg length and number of runs. For semi-automatic, automatic and mechanized welding, the size of electrode, welding current, arc voltage, speed of travel, wire feed speed, electrode extension or fillet weld leg length and number of runs and rate of flow of gas and/or consumption of other process materials, as appropriate. When applicable, the temperature and time adopted for drying/baking of welding consumables before use.
- g) Sketch showing edge preparation, fit-up and approximate number and arrangement of runs in multi-run welds.
- h) Jigging or tacking, backing, etc.
- i) Welding positions.
- j) Welding sequence.
- k) Minimum preheating temperature and interpass temperature range.
- l) Back gouging.
- m) Post-weld heat treatment.
- n) Any other relevant information (see Appendix D for guidance on fracture toughness of heat-affected zone and weld metal).

Welders shall be provided with sufficient information to enable the welding procedure to be carried out satisfactorily.

21 Welding procedures to avoid cracking

21.1 General. In determining welding procedures consideration shall be given to the avoidance of the following:

- a) hydrogen induced delayed cold cracking (see **21.2** and, for guidance, Appendix E);
- b) solidification cracking (for guidance see Appendix F);
- c) lamellar tearing (for guidance see Appendix G).

21.2 Procedures for avoiding hydrogen cracking

21.2.1 Introduction. Welding conditions for avoiding hydrogen cracking in carbon manganese steels have been drawn up in graphical form in Figure 4 for the normal range of compositions, expressed as carbon equivalent, covered by this standard and these conditions shall be followed whenever practicable. (See also **21.2.7**.)

NOTE The conditions have been drawn up to take account of differences in behaviour between different steels of the same carbon equivalent (making allowances for scatter in hardenability) and of normal variations between ladle and product analysis. They are valid for the avoidance of both heat-affected zone and weld metal cracking in the majority of welding situations. In some cases, the procedures determined in accordance with this clause may not be adequate to avoid hydrogen cracking and guidance on situations which may require more stringent procedures to avoid hydrogen cracking is given in Appendix E together with recommendations for these procedures.

21.2.2 Carbon equivalent values. The carbon equivalent values in Table 2 provide a good basis for the derivation of a welding procedure when using a steel complying with BS 4360. Where mill sheets indicate a higher carbon equivalent than Table 2 they shall form the basis for the procedure.

NOTE Where mill sheets are available which show a lower carbon equivalent they may be used as a basis for a less stringent procedure (but see **E.3**).

If, of the elements in the formula in clause 4 for calculating carbon equivalent, only carbon and manganese are stated on the mill sheet, then 0.03 shall be added to the calculated value to allow for residual elements. Where steels of different carbon equivalent or grade are being joined, the higher carbon equivalent value shall be used.

21.2.3 Hydrogen scales. The hydrogen scale to be used for any arc welding process depends principally on the weld diffusible hydrogen content and shall be as given in Table 1. The value used shall be that stated by the consumable manufacturer in accordance with the relevant standard where it exists (or as independently determined) in conjunction with a specified condition of supply and treatment.

NOTE Guidance on the use of hydrogen scales for various processes is given in E.2.

21.2.4 Preheating. The preheating temperature is the temperature of the parent metal immediately before welding commences, the same value frequently being used as the minimum interpass temperature for multi-run welds. Multi-run welds may have a lower permitted interpass temperature than the preheat temperature where subsequent runs are larger than the root run and in these cases the interpass temperature shall be determined from Figure 4 for the larger run.

Where preheating is applied local to the joint preparation, the required temperature shall exist in the parent metal for a distance of at least 75 mm in any direction from the joint preparation. Where practicable, the temperature shall be measured on the face opposite to that being heated. Otherwise, the temperature shall be confirmed on the heated face at a time after removal of the heat source, related to parent metal thickness to allow for temperature equalization. Where fixed permanent heaters are in use and there is no access to the reverse face for temperature measurement, readings shall be taken on the exposed parent metal surface immediately adjacent to the weld preparation.

NOTE The time allowed for temperature equalization should be of the order of 2 min for each 25 mm of parent metal thickness.

21.2.5 Combined thickness. Combined thickness shall be determined as the sum of the parent metal thicknesses averaged over a distance of 75 mm from the weld line (see Figure 3).

NOTE If the thickness increases greatly just beyond 75 mm from the weld line, it may be necessary to use a higher combined thickness value.

21.2.6 Arc energy. Arc energy values (in kJ/mm) for use with Figure 4 shall be calculated as follows, with an appropriate factor applied for processes other than manual metal-arc welding with covered electrodes:

$$\frac{VI}{w} \times 10^{-3}$$

where

- V* is the arc voltage (in V)
- I* is the welding current (in A)
- w* is the welding speed (in mm/s).

NOTE For guidance in using other welding processes, the arc energy values calculated from this formula should be divided by the following factors to give the values to be used in Figure 4:

- Submerged arc welding (single wire) : 0.8
- MIG/MAG welding (solid, cored or self-shielded wire) : 1.0
- TIG welding : 1.2

21.2.7 Simplified conditions for manual metal-arc welding. For the manual metal-arc welding of fillet welds the data obtainable from Figure 4 have been presented in tabular form for particular carbon equivalent values in Table 3 to Table 9.

For manual metal-arc welding with covered electrodes, arc energy values are expressed in Table 10, Table 11 and Table 12 in terms of electrode size, weld run length and runout ratio.

NOTE Where single run minimum leg length fillet welds are specified in the design, Table 13 may be used to obtain the approximate arc energy values for use in determining welding procedures from Table 3 to Table 9 or from Figure 4. These values are appropriate for the practical situation when a contractor is required to make single run fillet welds of a specified dimension related to the minimum leg length of the fillet welds and where in practice the second leg will be longer than the minimum, as for example in a horizontal-vertical fillet weld. In other cases arc energy should be controlled by control of electrode runout (Table 10, Table 11 and Table 12) or directly through welding parameters.

21.3 Alternative procedures. When alternative procedures are proposed the evidence shall include consideration of all the factors used in determining welding procedures as given in 21.2.

NOTE Conditions which might justify modifications to normal welding procedures to avoid hydrogen cracking are mentioned in Appendix E.

Table 1 — Hydrogen scales

Diffusible hydrogen content		Hydrogen scale
mL/100 g of deposited metal		
Over	Up to and including	
15	—	A
10	15	B
5	10	C
—	5	D

NOTE See E.3 for use of hydrogen levels below 2.5 mL/100 g of deposited metal.

Table 2 — Carbon equivalent values for BS 4360 steels to be used in absence of mill sheets

Steel grade	Plates and other than structural hollow sections			Structural hollow sections		
	Carbon equivalent value	Manual metal-arc fillet welds refer to table: ^a	Other than manual metal-arc fillet welds, refer to figure: ^a	Carbon equivalent value	Manual metal-arc fillet welds, refer to table: ^a	Other than manual metal-arc fillet welds, refer to figure: ^a
All 40 and 43 grades	0.40	4	4(a), (b) and (d)	0.40	4	4(a), (b) and (d)
50A, B and C	0.45	7	4(a), (e), (g) and (h)	0.45	7	4(a), (e), (g) and (h)
50B and C (CR)	0.41	5	4(b), (c) and (e)	n/a	n/a	n/a
50D	0.41	5	4(b), (c) and (e)	0.45	7	4(a), (e), (g) and (h)
50D1 and E	0.41	5	4(b), (c) and (e)	0.45	7	4(a), (e), (g) and (h)
50F (Q and T)	0.35	—	—	n/a	n/a	n/a
55C	0.45	7	4(a), (e), (g) and (h)	0.50	9	4(e)
55E (N)	0.48	8	4(c)	0.50	9	4(e)
55E and F (CR)	0.43	6	4(c), (e) and (g)	n/a	n/a	n/a
55E and F (Q and T)	0.38	3	4(b)	n/a	n/a	n/a

^a For information only.

Table 3 — Conditions for manual metal-arc welding with covered electrodes of fillet welds in steel having maximum carbon equivalent of 0.38

Hydrogen scale (see Table 1)	Specified minimum leg length ^a (see Table 13)	Minimum arc energy ^a , based on Table 13	Minimum preheating temperature for welding plates of following combined thicknesses								
			20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	Unlimited ^b
Scale A	mm	kJ/mm	°C	°C	°C	°C	°C	°C	°C	°C	°C
	4	1.0	0	0	0	0	50	75	100	100	100
	5	1.4	0	0	0	0	0	0	20	50	50
	6	2.0	0	0	0	0	0	0	0	0	0
	8	2.8	0	0	0	0	0	0	0	0	0
	10	3.8	0	0	0	0	0	0	0	0	0
Scale B, C or D	4	1.3	0	0	0	0	0	0	0	0	0
	5	1.7	0	0	0	0	0	0	0	0	0
	6	2.2	0	0	0	0	0	0	0	0	0
	8	3.4	0	0	0	0	0	0	0	0	0
	10	5.0	0	0	0	0	0	0	0	0	0

^a For individual run.
^b In situations of high restraint, a higher preheating temperature may nevertheless be necessary to avoid weld metal hydrogen cracking (see Appendix E).

Table 4 — Conditions for manual metal-arc welding with covered electrodes of fillet welds in steel having maximum carbon equivalent of 0.40

Hydrogen scale (see Table 1)	Specified minimum leg length ^a (see Table 13)	Minimum arc energy ^a , based on Table 13	Minimum preheating temperature for welding plates of following combined thicknesses								
			20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	Unlimited ^b
Scale A	mm	kJ/mm	°C	°C	°C	°C	°C	°C	°C	°C	°C
	4	1.0	0	0	0	50	100	125	125	125	125
	5	1.4	0	0	0	0	20	75	100	100	100
	6	2.0	0	0	0	0	0	0	20	50	50
	8	2.8	0	0	0	0	0	0	0	0	0
Scale B	10	3.8	0	0	0	0	0	0	0	0	0
	4	1.3	0	0	0	0	0	20	50	50	50
	5	1.7	0	0	0	0	0	0	0	0	0
	6	2.2	0	0	0	0	0	0	0	0	0
	8	3.4	0	0	0	0	0	0	0	0	0
Scale C or D	10	5.0	0	0	0	0	0	0	0	0	0
	4	1.3	0	0	0	0	0	0	0	0	0
	5	1.7	0	0	0	0	0	0	0	0	0
	6	2.2	0	0	0	0	0	0	0	0	0
	8	3.4	0	0	0	0	0	0	0	0	0
	10	5.0	0	0	0	0	0	0	0	0	0

^a For individual run.
^b In situations of high restraint, a higher preheating temperature may nevertheless be necessary to avoid weld metal hydrogen cracking (see Appendix E).

Table 5 — Conditions for manual metal-arc welding with covered electrodes of fillet welds in steel having maximum carbon equivalent of 0.41

Hydrogen scale (see Table 1)	Specified minimum leg length ^a (see Table 13)	Minimum arc energy ^a , based on Table 13	Minimum preheating temperature for welding plates of following combined thicknesses								
			20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	Unlimited ^b
Scale A	mm	kJ/mm	°C	°C	°C	°C	°C	°C	°C	°C	°C
	4	1.0	0	0	50	100	125	125	125	125	125
	5	1.4	0	0	0	0	50	100	100	125	125
	6	2.0	0	0	0	0	0	0	50	75	100
	8	2.8	0	0	0	0	0	0	0	0	0
	10	3.8	0	0	0	0	0	0	0	0	0
Scale B	4	1.3	0	0	0	0	20	50	75	100	100
	5	1.7	0	0	0	0	0	0	20	50	50
	6	2.2	0	0	0	0	0	0	0	0	0
	8	3.4	0	0	0	0	0	0	0	0	0
	10	5.0	0	0	0	0	0	0	0	0	0
Scale C	4	1.3	0	0	0	0	0	20	50	50	50
	5	1.7	0	0	0	0	0	0	0	0	0
	6	2.2	0	0	0	0	0	0	0	0	0
	8	3.4	0	0	0	0	0	0	0	0	0
	10	5.0	0	0	0	0	0	0	0	0	0
Scale D	4	1.3	0	0	0	0	0	0	0	0	0
	5	1.7	0	0	0	0	0	0	0	0	0
	6	2.2	0	0	0	0	0	0	0	0	0
	8	3.4	0	0	0	0	0	0	0	0	0
	10	5.0	0	0	0	0	0	0	0	0	0

^a For individual run.
^b In situations of high restraint, a higher preheating temperature may nevertheless be necessary to avoid weld metal hydrogen cracking (see Appendix E).

Table 6 — Conditions for manual metal-arc welding with covered electrodes of fillet welds in steel having maximum carbon equivalent of 0.43

Hydrogen scale (see Table 1)	Specified minimum leg length ^a (see Table 13)	Minimum arc energy ^a , based on Table 13	Minimum preheating temperature for welding plates of following combined thicknesses								
			20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	Unlimited ^b
Scale A	mm	kJ/mm	°C	°C	°C	°C	°C	°C	°C	°C	°C
	4	1.0	0	20	100	125	125	150	150	150	150
	5	1.4	0	0	0	75	100	125	125	150	150
	6	2.0	0	0	0	0	20	75	100	100	125
	8	2.8	0	0	0	0	0	0	0	50	50
	10	3.8	0	0	0	0	0	0	0	0	0
Scale B	4	1.3	0	0	0	20	75	100	125	125	125
	5	1.7	0	0	0	0	0	50	75	100	100
	6	2.2	0	0	0	0	0	0	0	50	75
	8	3.4	0	0	0	0	0	0	0	0	0
	10	5.0	0	0	0	0	0	0	0	0	0
Scale C	4	1.3	0	0	0	0	20	50	75	100	100
	5	1.7	0	0	0	0	0	0	20	50	50
	6	2.2	0	0	0	0	0	0	0	0	0
	8	3.4	0	0	0	0	0	0	0	0	0
	10	5.0	0	0	0	0	0	0	0	0	0
Scale D	4	1.3	0	0	0	0	0	0	0	0	0
	5	1.7	0	0	0	0	0	0	0	0	0
	6	2.2	0	0	0	0	0	0	0	0	0
	8	3.4	0	0	0	0	0	0	0	0	0
	10	5.0	0	0	0	0	0	0	0	0	0
^a For individual run.											
^b In situations of high restraint, a higher preheating temperature may nevertheless be necessary to avoid weld metal hydrogen cracking (see Appendix E).											