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Guidance for arc welding of reinforcing steel

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Contents

Summary of pages

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Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31st January 2017. It was prepared by Technical Committee WEE/43, *Welding of steel for concrete reinforcement*. A list of organizations represented on this committee can be obtained on request to its secretary.

Test laboratory accreditation. Users of this British Standard are advised to consider the desirability of selecting test laboratories that are accredited to BS EN ISO/IEC 17025 by a national or international accreditation body.

Use of this document

As a guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The guidance in this standard is presented in roman (i.e. upright) type. Any recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

This standard has been prepared with the aim of clarifying the requirements and providing suitable guidance for the arc welding of carbon steel reinforcing bars produced in accordance with BS 4449 and BS 4482. This standard has been developed to reflect current best welding practice, standards and specifications.

This standard also gives recommendations and guidance on friction welding in Annex A.

This standard gives general guidance for the satisfactory production and control of the welding of steel reinforcement in accordance with the requirements of BS EN 1011-2, BS EN ISO 17660-1 and BS EN ISO 17660-2. In order to aid the specifier and manufacturer using these standards, additional informative guidance has been added, especially regarding the steps to be taken to avoid hydrogen cracking.

The procedures and test requirements contained in this standard apply to the assessment of the weld and its potential effect on the welded reinforcement but do not take into account design criteria, e.g. fatigue, that are the responsibility of the relevant application standard.

The preferred method of control of welding is under factory conditions. Construction site welding, if conducted, should be carried out under similar controlled conditions.

These and other products give the designer a broad range of options for specifying pre-assembled welded fabrications.

Reinforcing steel bars manufactured in accordance with the requirements of BS 4449 and BS 4482 are produced by a number of differing process routes, typically quenched and self-tempered, cold reduced and to a lesser extent micro-alloyed steel. In addition to this the profile of the reinforcement bar is ribbed and as such the welding of steel reinforcement requires a specific level of skill and job knowledge, both for the welder and the organization exercising control over the whole process, from purchasing of the steel to the eventual supply of the prefabricated item to the customer.

Whilst the specific requirements for the welding of steel reinforcement are set out in BS EN ISO 17660-1 and BS EN ISO 17660-2, this standard gives general guidance for the satisfactory production and control of welding and details some of the possible detrimental phenomena which might occur, with advice on the methods by which they can be avoided.

The recommendations in this standard are relevant to the metal arc welding processes, which are commonly used for the welding of reinforcing steels, although other welding processes may be used by agreement between the contracting parties.

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1 Scope

This British Standard gives guidance for the metal arc welding of reinforcing steel bars produced in accordance with BS 4449 and BS 4482 and welded in accordance with the requirements of BS EN ISO 17660-1 and BS EN ISO 17660-2.

The welding of stainless reinforcing steels is not covered by this standard.

This British Standard can be used by clients, specifiers, construction companies and fabricators of welded steel reinforcement as a means of agreeing the technical requirements of welded steel reinforcement.

This standard applies to the welding of load bearing joints (structural and semi-structural) and non-load bearing joints, including prefabricated assemblies, produced either in a factory, workshop or in a site environment. It also applies to the welding of reinforcing steels to other steel components such as connection devices, inserts, and anchors.

This standard gives recommendations on the information to be included in the Project Specification and also covers the materials of construction, methods for the approval of welding procedures and welding, workmanship, inspection, testing and acceptance requirements for the welded joints. It can be used for all types of reinforced concrete structures designed for static loading conditions.

The recommendations in this standard can be introduced into a construction contract by a Project Specification.

This standard does not apply to factory production of welding fabric and lattice girders using multiple spot welding machines. Annex A addresses the requirements for the friction welding of steel products to reinforcement.

This standard gives general guidance on joints between reinforcing steels and other steel components. It only includes more detailed information on the most commonly used joints.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 4449:2005+A3:2016, *Steel for the reinforcement of concrete – Weldable reinforcing steel – Bar, coil and decoiled product – Specification*

BS 4482, *Steel wire for the reinforcement of concrete products – Specification*

BS EN 1011-2:2001, *Welding – Recommendations for welding of metallic materials – Part 2: Arc welding of ferritic steels*

BS EN 10020:2000, *Definition and classification of grades of steel*

BS EN ISO 2553, *Welding and allied processes – Symbolic representation of drawings – Welded joints*

BS EN ISO 3834-2, *Quality requirements for fusion welding of metallic materials – Comprehensive quality requirements*

BS EN ISO 4063:2010, *Welding and allied processes – Nomenclature of processes and reference numbers*

BS EN ISO 5817, *Welding – Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) – Quality levels for imperfections*

BS EN ISO 9015-1, *Destructive tests on welds in metallic materials – Hardness testing – Part 1: Hardness test on arc welded joints*

BS EN ISO 9606-1:2013, *Qualification testing of welders – Fusion Welding – Part 1: Steels*

BS EN ISO 13916, *Welding – Guidance on the measurement of preheating temperature, interpass temperature and preheat maintenance temperature*

BS EN ISO 14731:2006, *Welding coordination – Tasks and responsibilities*

BS EN ISO 15613:2004, *Specification and qualification of welding procedures for metallic materials – Qualification based on pre-production welding test*

BS EN ISO 15614-1, *Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

BS EN ISO 15620, *Welding – Friction welding of metallic materials*

BS EN ISO 15630-1, *Steel for the reinforcement and prestressing of concrete – Test methods – Part 1: Reinforcing bars, wire rod and wire*

BS EN ISO 15630-2, *Steel for the reinforcement and prestressing of concrete – Test methods – Part 2: Welded fabric*

BS EN ISO 17639, *Destructive tests on welds in metallic materials – Macroscopic and microscopic examination of welds*

BS EN ISO 17660-1, *Welding – Welding of reinforcing steel – Part 1: Load-bearing welded joints*

BS EN ISO 17660-2, *Welding – Welding of reinforcing steel – Part 2: Non load-bearing welded joints*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1.1 company welding coordinator

person or persons responsible for ensuring that welding is performed in accordance with the defined welding conditions, procedures and practices

3.1.2 customer

individual, or company, placing the contract with the manufacturer

3.1.3 factory

suitably enclosed rigid structure, consisting of a solid floor, walls and ceilings and constructed from recognized construction materials, providing a weatherproof envelope for the assembled products being welded so as to protect them from deleterious environmental factors such as wind, rain and snow

3.1.4 load bearing welded joint

welded joint for the transmission of specified loads between reinforcing steel bars, or between a reinforcing steel bar and other steel products

NOTE There are two types of load bearing welded joints in pre-assembled welded fabrications: semi-structural joints and structural joints.

3.1.5 manufacturer

enterprise carrying out the welding works within workshops or on site

3.1.6 non-load bearing welded joint
welded joint whose strength is not taken into account in the design of the reinforced concrete structure

NOTE 1 These welds are also referred to as locational welds.

NOTE 2 The purpose of these joints is normally only to keep the reinforcing components in place during fabrication, transport and concreting.

3.1.7 responsible welding coordinator
person or persons responsible for defining the welding conditions, procedures and practices

3.1.8 semi-structural joint
joint designed to support loads during transport and placement at the construction site to ensure safe handling, lifting, transport and use of the fabricated structure

3.1.9 shear factor S_f
relationship between the shear force of a cruciform joint and the nominal yield strength multiplied by the nominal cross-sectional area of the loaded bar

3.1.10 site welding
welding that takes place without a structure to provide a weatherproof envelope

NOTE In these instances of unprotected welding, extreme care needs to be taken to ensure that the ambient conditions are conducive to welding.

3.1.11 structural joint
joint designed to support loads during service

3.1.12 workshop
rigid structure that is capable of providing a weatherproof envelope for both welder and welds so as to protect them from deleterious environmental factors such as wind, rain and snow

NOTE The weatherproof envelope would also be expected to protect the piece, parts and stock used to manufacture the welded structure.

3.2 Symbols and abbreviations

For the purposes of this British Standard, the following symbols and abbreviations in Table 1 apply.

Table 1 **Symbols and abbreviations** *(1 of 2)*

Symbol	**Description**	**Unit**
A_n	nominal cross-sectional area of the bar	mm^2
A_{gt}	percentage total elongation at maximum force	%
a	weld throat thickness	mm
C_{eq}	carbon equivalent value	%
D	nominal diameter of the welded bar	mm
d	thickness of steel components	mm
d_{max}	nominal diameter of the largest bar size in the welded joint	mm
d_{min}	nominal diameter of the smallest bar size in the welded joint	mm
l	length of weld	mm
R_e	specified characteristic yield strength of the reinforcing steel bar	N/mm^2

Table 1 **Symbols and abbreviations** *(2 of 2)*

R_m	nominal tensile strength of the reinforcing steel bar	N/mm^2
F_s	shear force	kN
S_f	shear factor	—
t	time	—
w	weld width	mm
WPQR	welding procedure qualification record	—
WPS	welding procedure specification	—

NOTE 1 If R_m is not specified for the parent metal, the value of R_m is to be taken as the specified characteristic yield strength R_e of the bar multiplied by the specified characteristic R_m/R_e ratio.

NOTE 2 Other symbols and abbreviated terms should be as specified in BS EN ISO 17660-1 and BS EN ISO 17660-2.

4 Information required by the manufacturer – Project specification

It is the responsibility of the customer to provide appropriate information for the intended works.

The following items, agreed between the contracting parties, should be fully documented. If not specified by the customer, they should be stated by the manufacturer.

a) Specification of the parent metal and of the required weld metal together with welded joint properties and details of any backing material.

b) Locations, dimensions and details, i.e. form of joint, gaps between parts etc. of all welds.

c) Examiner responsible for qualification of weld test procedures (see Note 1).

d) Examiner responsible for qualification and testing of welders (see Note 1).

e) The method and extent of inspection and testing and the quality requirements (see Clause **9**).

f) The project specification should clearly identify if there is a design requirement, including temporary works design, and who is responsible for the design.

g) Agreed weld quality acceptance levels (see **7.4**).

h) Quality management system requirements.

i) Whether third party approval is required by the customer.

*NOTE Testing of welding procedures and welders can be undertaken by an independent testing laboratory or authority (see Clause **7**). Users of this British Standard are advised to consider the desirability of selecting test laboratories that are accredited to BS EN ISO/IEC 17025 by a national or international accreditation body.*

Other additions and deviations may be agreed between the contracting parties.

When symbols are used for standard weld forms, they should conform to BS EN ISO 2553 and BS EN ISO 4063.

In the event of a conflict in specified requirements, the Project Specification takes precedence over other documents.

5 Materials – Parent materials

5.1 Reinforcing steels

Reinforcing steels should conform to the requirements of BS 4449 or BS 4482.

5.2 Other steel components

Other steel components should have carbon equivalent, sulphur and phosphorus levels not greater than those specified in 7.1 of BS 4449:2005+A3 and in BS 4482 for the reinforcing steel being welded. Other steel components may include hot rolled products of structural steels in accordance with BS EN 10025.

5.3 Material test certificates

All the steels being welded should have a material test certificate available which should include the carbon equivalent value (C_{eq}) and the manufacturing process route.

5.4 Welding consumables

5.4.1 General

Welding consumables should be designated in accordance with the relevant product standard. Consumables should be selected with regard to the particular application, e.g. joint design, welding position and the properties required to meet the service conditions. Any special recommendations given by the manufacturer/supplier should be observed.

Many welding consumables are now required to be CE marked and relevant documentation should be verified before use of materials.

5.4.2 Supply, storage and handling

All consumables should be stored and handled with care and in accordance with the relevant standards and/or the manufacturer's/supplier's recommendations.

All covered electrodes, wire electrodes, rods and fluxes, etc. as well as their packaging, which show signs of damage or deterioration should not be used.

NOTE Examples of damage or deterioration are cracked or flaked coatings on covered electrodes, rusty or dirty wire electrodes and wire with flaked or damaged protective coatings.

Consumables returned to the stores should be treated in accordance with the manufacturer's/supplier's recommendations before re-issue.

6 Workmanship – Welding processes and joints

6.1 Welding processes

The welding processes covered by this standard are listed in Table 2. Other welding processes may be used by agreement between the contracting parties.

Table 2 **List of most common welding processes**

Welding process – Ref No. from BS EN ISO 4063	Term
111	metal-arc welding with covered electrode (MMA)
131	metal-arc inert gas welding (MIG welding)
135	metal-arc active gas welding (MAG welding)

6.2 Welded joints

6.2.1 General

The most common range of bar diameters for welded joints using the welding processes given in **6.1** is 10 mm to 50 mm. The joints described in **6.2.2**, **6.2.3** and **6.2.4** are examples of good practice but other joint configurations may be used, by agreement between the two contracting parties if they can be shown to meet the Project Specification.

Load bearing welded joints are designed to give a specified load bearing capacity either in service (structural joints) or for lifiting of the assembled reinforcement unit (semi-structural joints).

For semi-structural joints, lifting points should be specified.

Wherever practicable the load capacity of a joint should be verified by testing the relevant joint configuration.

Non-load bearing joints are used to hold together assemblies of reinforcing bars for locational purposes only and should not be relied upon for safe handling, lifting and transport.

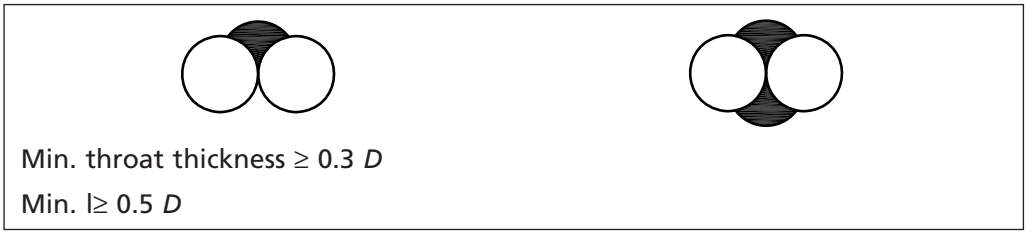
6.2.2 Lap joints

Lap joints should be made with flare vee fillet welds, as shown in Figure 1.

The minimum throat thickness for lap joints should be 0.3 D_{min}. For load bearing joints the minimum weld length should be 4 D_{min}.

NOTE The use of double flare vee fillet welds rather than single flare vee fillet welds minimizes bar overlap.

Figure 1 **Lap joints**



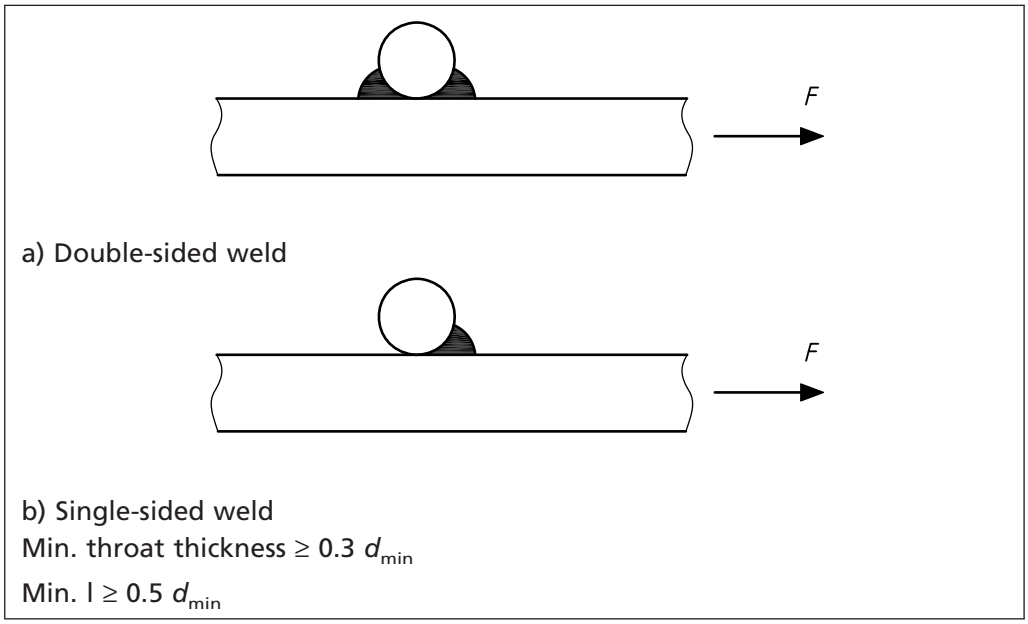
6.2.3 Cruciform joints (Cross joints)

Cruciform joints should be made with flare bevel fillet welds, which can be intermittent or continuous.

The minimum throat thickness for cruciform joints should be 0.3 d_{min}. For load bearing joints the minimum weld length should be 0.5 d_{min}.

If a one-sided weld is used, the verification of the shear strength of the welded joint should be made with the applied force as shown in Figure 2.

Figure 2 **Cruciform joint**



6.2.4 Joints between reinforcing steels and other steel components

Where reinforcing steel is to be joined to steel components by butt or fillet welds, the welding should follow the guidance in this standard and, where relevant, with BS EN 1011-2. The choice of material, filler metal, calculation and design of the steel component should be in accordance with the relevant Project Specification.

6.3 Welding coordination

The manufacturer should have at least one responsible welding coordinator as set out in BS EN ISO 14731 with general and specific technical knowledge in the welding of reinforcing steel products, see Annex B for more detail on the role and relevant competencies. The role of the responsible welding coordinator may be subcontracted although in this case the responsibility for following the guidance of this standard should remain with the manufacturer through the company welding coordinator. Where welding coordination is carried out by more than one person then for the essential welding-related tasks, as defined in BS EN ISO 14731:2006 Annex B, the responsibilities should be clearly defined, ensuring that the particular coordinator is qualified for each specific welding coordination task.

The welding coordination personnel should be responsible for the quality of the welded reinforcing steel joints and should ensure that welding is only performed in accordance with approved welding procedure specifications (WPS) and by welders approved by the manufacturer. The WPS should be available for inspection at the place of welding.

The manufacturer's company welding coordinator may supervise the welder qualification tests for those welders under their control during the execution of the welding activities. The responsible welding coordinator may issue and prolong welder's qualification test certificates for the welding of reinforcing steels.

The roles of the responsible welding coordinator and company welding coordinator may be covered by one suitably qualified individual.

7 Welding procedure specification (WPS) and qualification testing

7.1 General

Welding procedures should be prepared in accordance with BS EN ISO 15613. An example of a welding procedure specification is given in Annex C.

Prior to production welding, all welding procedures should be qualified by a welding procedure test.

7.2 Test pieces

The appropriate test pieces should be as identified in Annex D.

7.3 Examination and testing

Examination and testing should be carried out in accordance with Table 3.

Table 3 **Tests required for welding procedure specification qualification**

Type of welded joint	Number of test pieces			
	Bar tensile test	Bend test	Weld shear test	Macro examination[A)]
Loading bearing weld joints				
Structural joints				
Lap joint	—	—	3[B)]	1
Cruciform joint	3[C)]	3[D)]	3[E)]	1
Semi-structural joints				
Lap joint	—	—	3[B)]	1
Cruciform joint (including steel plate to reinforcing bar)	3[C)]	1[D)]	2[E)]	1
Other joint configurations may be used by agreement between the two contracting parties if they can be shown to meet BS EN ISO 15613 and the Project Specification.				
Non-load bearing welded joints				
Locational welded lap joint	—	—	3[B)]	1
Locational welded cruciform joint	3[C)]	—	—	1

[A)] The macro examination includes a hardness survey in accordance with BS EN ISO 15614-1.
[B)] Tested in accordance with Figure D.3.
[C)] Tensile test on the thinnest bar or bar if welded to plate.
[D)] The bend test is only necessary when the weld zone is bent in production and when required should be on the thicker bar.
[E)] Shear test on the bar to be anchored. Tested in accordance with Figure D.2.

7.4 Acceptance criteria

The acceptance criteria for examination and testing should meet the requirements given in BS EN ISO 15614-1 and BS EN ISO 5817, level C for surface (Table 4) and internal imperfections (Table 5).

Table 4 **Surface imperfection acceptance levels – Visual inspection**

Reference No. from BS EN ISO 5817	Imperfection designation	Limits for imperfections
1.1	Crack	Not permitted
1.2	Crater crack	Not permitted
1.3	Surface pore	Less than 0.2 × weld throat with a maximum of 2 mm; multiple pores not permitted
1.5	Lack of fusion	Not permitted
1.7	Undercut	0.5 mm intermittent, continuous undercut not permitted
1.9	Excess weld metal	Less than or equal to 1 mm + 15% of weld bead width, 7 mm max. (butt weld only)
1.13	Overlap	Not permitted

NOTE Further criteria may be selected from BS EN ISO 5817 by agreement between the contracting parties.

Table 5 **Internal imperfection acceptance levels – Macro-examination**

Reference No. from BS EN ISO 5817	Imperfection designation	Limits for imperfections
2.1	Crack	Not permitted
2.7	Shrinkage cavity	Not permitted
2.11	Copper inclusions	Not permitted
2.12	Lack of fusion	Not permitted
2.13	Lack of penetration (butt weld)	Not permitted
1.13	Overlap	Not permitted

NOTE Further criteria may be selected from BS EN ISO 5817 by agreement between the contracting parties.

When hardness tested in accordance with BS EN ISO 15614-1, no single value should exceed 380 HV_{10}. A typical example of a hardness profile is shown in Annex E.

7.5 Range of qualification

7.5.1 Material

A welding procedure test carried out on one steel strength grade does not qualify for other steel strength grades.

The carbon equivalent value for the material used during the weld procedure test qualifies materials of an equal or lower carbon equivalent value, but not those with higher carbon equivalents.

7.5.2 Load bearing/non-load bearing joints

A welding procedure test carried out on a load bearing joint should qualify for the procedure for non-load bearing joints.

A welding procedure test carried out on a structural weld should qualify for the procedure for a semi-structural weld.

7.5.3 Manufacturing process route of reinforcing steel

A welding procedure qualification should only be valid for the manufacturing process route of the reinforcing steel used in the welding procedure test.

7.5.4 Diameter of reinforcing steel bar and material thickness

The ranges of qualification of diameter of reinforcing steel bar and material thickness are given in Table 6.

The range of qualification of diameter given in Table 6 only applies when all other variables (such as electrode type and diameter, voltage, current, heat input, shielding gas flow rate etc.) remain unchanged.

Table 6 **Ranges of qualification of diameter of reinforcing steel bar and material thickness**

Diameter and plate thickness used for the welding procedure test[A)]	**Range of qualification**[B)]
D/D	One nominal diameter up and down for bars of equal diameter[C)]
D_{max}/D_{min}	Only joint combination tested
D_{max}/D_{max} D_{min}/D_{min}	All joints between D_{max} and D_{min} for bars of equal diameter
D_{max}/D_{max} D_{min}/D_{min} D_{max}/D_{min}	All combinations of bar diameter from D_{min} to D_{max}

Joints with other steel components

Steel bar	**Material thickness**	**Steel bar**	**Material thickness**
	mm		mm
D_{max} and D_{min}	$4 < d < 30$ $d \geq 30$	D_{max} to D_{min}	0.5 d (4 min.) to 1.2 d $d \geq 5$

[A)] For test pieces of differing bar diameters, both bar diameters should be tested.

[B)] For bar diameters over 32 mm, each diameter should be tested.

[C)] Nominal diameter is defined in BS 4449 and BS 4482.

7.5.5 Other essential variables

The range of qualification for other essential variables should meet the requirements of BS EN ISO 15614-1.

7.5.6 Validity of qualification

Welding procedures should be restricted to the manufacturer named on the WPQR and should remain under the same technical and quality control to remain valid. Welding procedures should not be transferred to another manufacturer.

The period of validity of the weld procedure test should not be limited, provided that regular production weld tests are undertaken. If there is an interruption in the production work for a period in excess of 12 months, then the weld procedure test should be revalidated by undertaking a pre-production test as specified in Table 3.

8 Welder qualification tests

8.1 Welder qualification

To perform load bearing welded joints on reinforcing steel bars, the welder should have passed a basic fillet weld qualification test in accordance with BS EN ISO 9606-1. In addition, the welder should have received training in the welding of the relevant reinforcement joint. The number of approval test pieces should be in accordance with Table 7, under the most critical welding position used in production, see Table 8 where 1 represents the least difficult and 4 represents the most difficult welding position. The evaluation of the test pieces should be in accordance with **7.4**. The range of approval according to welding position should conform to BS EN ISO 9606-1:2013, Table 10. Welder qualification testing should be undertaken.

Table 7 **Tests required for welder qualification of each WPS**

Type of welded joint	Number of test pieces		
	Bar tensile test [A)]	Weld shear test	Macro examination [B)]
Load bearing welded joints			
Structural joints			
Lap joint	—	3[C)]	1
Cruciform joint	3	3[D)]	1
Semi-structural joints			
Lap joint	—	3[C)]	1
Cruciform joint (including steel plate to reinforcing bar)	3	2[D)]	1
Other joint configurations may be used by agreement between the two contracting parties if they can be shown to meet the Project Specification.			
Non-load bearing welded joints			
Locational welded lap joint	—	1[C)]	1
Locational welded cruciform joint	1	—	1

[A)] Tensile test on the thinnest bar or bar if welded to plate.
[B)] The macro examination includes a hardness survey in accordance with BS EN ISO 15614-1.
[C)] Tested in accordance with Figure D.3.
[D)] Shear test on the bar to be anchored. Tested in accordance with Figure D.2.

Table 8 **Relationship between welding position and degree of difficulty**

Connection type	Welding position			
Fillet	PA (1F)	PB (2F)	PF (3F)	PD (4F)
	Down hand	Horizontal	Vertical up	Overhead
Difficulty	1	2	3	4

8.2 Validity of welder qualification test

A welder qualified in accordance with Clause **8** should remain qualified within the range of the original qualification for three years, provided the welder is confirmed as having worked in the range of qualification every six months. After this time, the welder should undertake the revalidation tests or the qualification may be prolonged in accordance with BS EN ISO 9606-1. For prolongation of the welder qualification for load bearing joints, records of at least eight production weld tests, welded in the most difficult position, should have been documented in the preceding 24 months. For prolongation of the welder qualification for semi-structural joints, records of at least four production weld tests, welded in the most difficult position, should have been documented in the preceding 24 months. For prolongation of the welder qualification for locational welded joints, records of at least four production weld tests should have been documented in the preceding 24 months. Prolongation of the plate fillet weld joint is not required.

8.3 Production weld test

A production weld test should be carried out to verify that the same quality of weld is produced under local fabrication conditions as for the weld procedure qualification. The number of test pieces required for each welder and WPS are set out in Table 9.

The production weld tests should be prepared in the most difficult welding position used during production.

In the case of routine work under factory conditions, weld tests should be undertaken at least every three months (structural joints) or six months (semi-structural joints). For welding under site conditions, tests should be taken at the start of the contract and every month thereafter.

Table 9 **Number of test pieces for production weld tests for each welder and WPS**

Types of welded joint	Number of test pieces			
	Bar tensile test	Bend test	Weld shear test	Macro examination
Load bearing welded joints				
Structural joints				
Lap joint	—	—	1	1
Cruciform joint	1[A)]	1[B)]	3[C)]	1
Semi-structural joints				
Cruciform joint (including steel plate to reinforcing bar)	1	—	1	1
Other joint configurations may be used, by agreement between the two contracting parties if they can be shown to meet the Project Specification.				
Non-load bearing welded joints				
Locational welded lap joints	1	—	—	1
Locational welded cruciform joints	1[A)]	—	—	1

[A)] Tensile test on the thinner bar diameter.

[B)] Bend test on the thinner bar.

[C)] Shear test on the bar to be anchored.

The test pieces should be welded and examined in accordance with the requirements of Clause **6**. If one test specimen fails, two additional test pieces produced under the same conditions should be welded and tested. Both additional test pieces should fulfil the requirements set out in Clause **6**. If one of these additional test pieces fails, then the production weld test fails and the appropriate corrective action should be taken, and a record of such actions should be retained.

In the case of a production weld test failure, the welder involved should be retrained as required prior to undertaking a further production weld test. Only after a successful weld test has been achieved may the welder recommence work.

The results of production weld tests should be retained for at least five years.

9 Execution and inspection of welding of reinforcing steel bars

9.1 General

The welding activity should be protected against meteorological influences that could affect the quality of the weld, such as wind, rain, snow, etc. Surfaces to be welded should be dry and whenever there is evidence of condensation on the material surface, this should be removed by warming. Welding should not be undertaken when the surface of the steel is below 5 °C.

The surfaces of the steel should be free from contamination that might adversely affect the quality of the weld such as moisture, grease, oil, corrosion, loose scale and paint. Surface contamination can be a source of hydrogen evolution during welding which can lead to embrittlement and possible cracking.

Welding should only be undertaken in accordance with the qualified WPS, which should be available at the place of welding.

Welding should only be undertaken by welders approved in accordance with the relevant WPS.

9.2 Weld quality

There should be a visual examination of the weld and any imperfections that are detected should be assessed against the requirements of Clause **7**. The existence of weld imperfections in excess of those specified in **7.4** should be cause for rejection.

9.3 Weldability factor

Whenever the welding conditions might affect the weldability (e.g. high cooling rates, susceptible chemical analysis or microstructure), suitable measures should be given in the WPS.

Guidance on the avoidance of hydrogen cracking is given in Annex F.

NOTE This guidance is in line with the guidance given in BS EN 1011-2.

Where preheating is required, the points of temperature measurement should be in accordance with BS EN ISO 13916 except that for all thicknesses the distance for measurement should be at least 75 mm from the weld centre line.

Particular attention should be paid to the need for preheating when making low heat input welds, e.g. locational welds.

9.4 Welding of bent reinforcing steel bars

Bending of reinforcing steel bars should be carried out before welding.

NOTE In special cases where welding is carried out after bending, BS EN 1992-1-1 gives requirements for mandrel diameters for bending reinforcing steel.

9.5 Production log

The manufacturer should keep a record of production or, in the case of site welding, the customer should keep the record. This record, termed the production log, should detail the WPS used, the results of production tests and relevant data, including the name of the welder and material cast number(s). The log should be maintained and made available at the place of work.

10 Quality management

10.1 Quality management system requirements

Manufacturers that perform welding of reinforcing steel bars should conform to the relevant requirements of BS EN ISO 3834-2.

The welding coordinator should audit the welding operations of the company prior to the commencement of production in accordance with this standard and record their findings.

10.2 Receipt, storage and use by the customer

Upon receipt of the pre-assembled welded fabrications at the construction site, it is the responsibility of the customer to implement effective procedures to ensure the pre-assembled welded fabrications are appropriately handled, stored and correctly fixed to avoid any defects in the permanent works.

In particular, when placing pile cages into position, the customer should ensure the correct lifting points are used to avoid intense point loading on the relatively flexible transverse links or rings. Once in place and after initial concrete casting, the customer should ensure that proper care is taken when breaking down reinforced concrete pile heads to avoid mechanical damage or fracture of the reinforcing bars.

Guidance on the appropriate temporary works methods of lifting, handling and working with pre-assembled welded fabrications should be obtained from the manufacturer.

When it is necessary to weld reinforcement at the construction site, the technical guidance described in this British standard should be satisfied in order to produce acceptable welds.

Annex A (informative) Friction welding of steel components to reinforcement bar

The friction welding of steel components to reinforcement bars, for example the friction welding of couplers, should be in accordance with BS EN ISO 15620. BS EN ISO 15620 sets out the requirements for friction welding machine requirements, WPS, welding procedure approval and the requirements for welding personnel including the welding coordinator.

The standard offers guidance for quality assurance. For reinforcement products Category A should be used where failure of welded components might be dangerous for the product and the environment. The recommended inspection and test requirements are set out in Table A.1.

Table A.1 **Recommended inspection and test requirements**

Visual examination	Check of total length loss	Parameter monitoring	Recording of parameters	Tensile test	Bend test
100%	100%	100%	100%	1 in 1 000 welds	1 in 3 000 welds

Annex B (informative) Welding coordinator competence

B.1 General

The role of welding coordination is an important role within an organization with respect to the satisfactory control of welding operations. The person(s) holding the positions of the responsible welding coordinator and company welding coordinator should be competent to undertake the specified tasks (see Table B.1).

Competence cannot be defined purely in terms of the qualifications held by any individual but rather a combination of skills, experience and knowledge. It is the responsibility of the organization producing the welded reinforcement to assess the competence of their welding coordination personnel. Table B.1 is for guidance only.

B.2 General knowledge requirements

An example of recommended qualification routes is given in Table B.1. [1)]

Table B.1 **General knowledge requirements for welding coordinator** *(1 of 2)*

Role within organization	International Institute of Welding (IIW) qualification route	The Welding Insitute (TWI) Professional Membership route	Certification Scheme for Personnel route (CSWIP)
Responsible welding coordinator	International Welding Specialist (IWS)	Incorporated Member (IncWeldI)	—

[1)] The International Institute of Welding, The Welding Institue and the Certification Scheme for Personnel are examples of suitable companies and training schemes available commercially. This information is given for the convenience of users of this standard and does not constitute an endorsement by BSI of these products.

Table B.1 **General knowledge requirements for welding coordinator** *(2 of 2)*

Role within organization	International Institute of Welding (IIW) qualification route	The Welding Insitute (TWI) Professional Membership route	Certification Scheme for Personnel route (CSWIP)
Company welding coordinator	—	Technician Member (TechWeldI)	CSWIP 3.1 Welding Inspector CSWIP Welding Quality Control Coordinator

NOTE Whilst the TWI and CSWIP routes require a level of post qualification experience and responsibility, this is not true for the IIW route and manufacturers might assess the level of experience of personnel qualified via this route.

B.3 Specific knowledge requirements

The welding coordination personnel require specific knowledge regarding the technical aspects of the welding of steel reinforcement, especially the various steel types and process routes used for the manufacture of steel reinforcement. Table B.2 gives guidance on the different responsibilities of the welding coordination personnel in relation to essential welding tasks.

Whilst it can be reasonably expected that the level of knowledge attained by the responsible welding coordinator is gained through experience, it is recommended that the welding coordinator undergo specific training in the welding of steel reinforcement.

Table B.2 **Guidance on the responsibilities of welding coordination personnel with respect to the essential welding-related tasks** *(1 of 2)*

Welding-related task (as defined in BS EN ISO 14731:2006)	Responsible welding coordinator	Company welding coordinator
B.1 Review of requirements	Primary responsibility	—
B.2 Technical review	Primary responsibility	—
B.3 Sub-contracting	Primary responsibility	—
B.4 Welding personnel	Primary responsibility	Supporting role
B.5 Equipment	Joint responsibility	Joint responsibility
B.6 Production planning	Joint responsibility	Joint responsibility
B.7 Qualification of the welding procedures	Primary responsibility	—
B.8 Welding procedure specification	Primary responsibility	—
B.9 Work instructions	Joint responsibility	Joint responsibility
B.10 Welding consumables	Joint responsibility	Joint responsibility
B.11 Materials	Joint responsibility	Joint responsibility
B.12 Inspection and testing before welding	—	Primary responsibility
B.13 Inspection and testing during welding	—	Primary responsibility
B.14 Inspection and testing after welding	—	Primary responsibility
B.15 Post-weld heat treatment	—	Primary responsibility
B.16 Non-conformance and corrective actions	Joint responsibility	Joint responsibility

Table B.2 **Guidance on the responsibilities of welding coordination personnel with respect to the essential welding-related tasks** *(2 of 2)*

Welding-related task (as defined in BS EN ISO 14731:2006)	Responsible welding coordinator	Company welding coordinator
B.17. Calibration and validation of measuring, inspection and testing equipment	—	Primary responsibility
B.18 Identification and traceability	Joint responsibility	Joint responsibility
B.19 Quality records	Joint responsibility	Joint responsibility

Annex C (informative) Example of a Welding Procedure Specification (WPS)

Table C.1 **Welding Procedure Specification (WPS)**

WPS ref. No.								
WPQR ref. No.					Method of preparation details*			
Manufacturer					Parent materials used			
Joint and weld type					Material diameter/thickness			
Mode of metal transfer					Welding position			
*sketch may be required.								
Joint design					Welding sequence			
Welding details								
Run	Welding process	Filler material size	Current A	Voltage V	Current type/ polarity	Wire feed speed	Run out length/ travel speed	Heat input*
* Calculated in accordance with BS EN 1011-1.								
Welding consumables/ Weld pre- and post-treatment								
Filler material					Preheat temperature			
Control of filler material					Interpass temperature			
Shielding gas/ flux type					Post weld heating regime			
Gas flow rate					Detail of backing material			
Special welding techniques to be used								
Name of Manufacturer								
Name of Responsible Welding Coordinator								
Signature of Responsible Welding Coordinator								
Date								

Annex D (informative) Welded test pieces

D.1 General

The test specimen configuration is given in Figures D.1 to D.4. The actual dimensions of the specimens should be agreed with the test laboratory.

D.2 Test pieces

Figure D.1 **Test piece for bar tensile tests and bend tests**

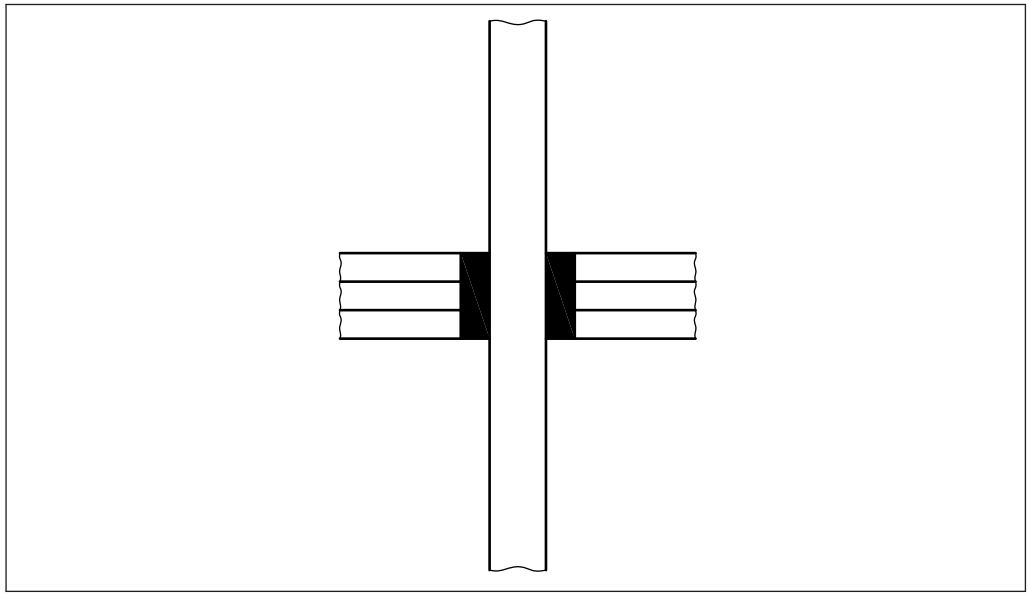
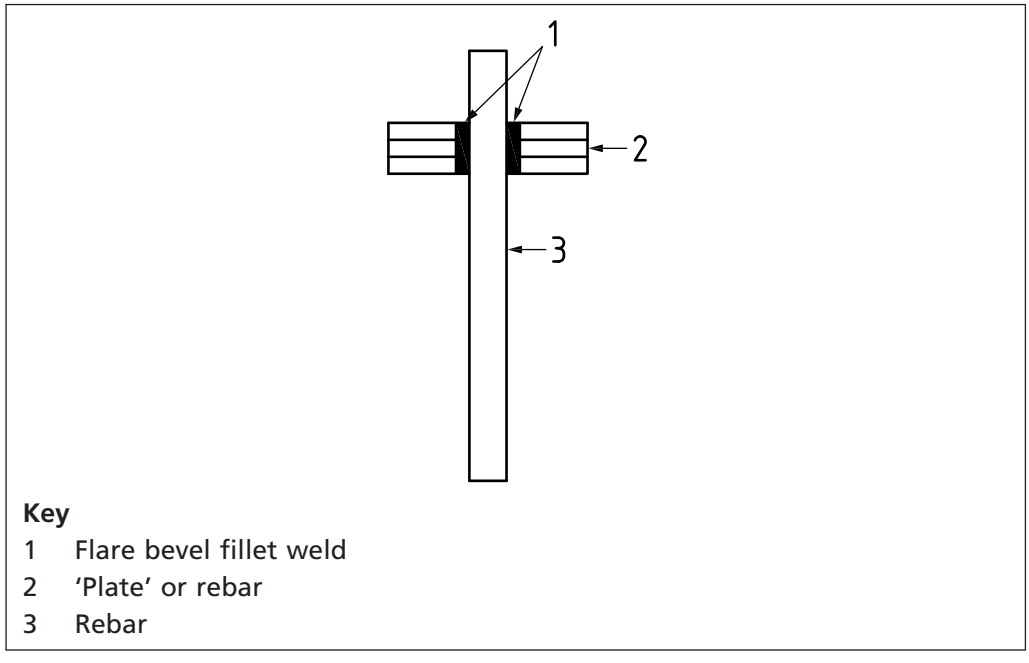


Figure D.2 **Test piece for weld shear test**



Key

1 Flare bevel fillet weld
2 'Plate' or rebar
3 Rebar

Figure D.3 **Test piece for a lap weld shear test**

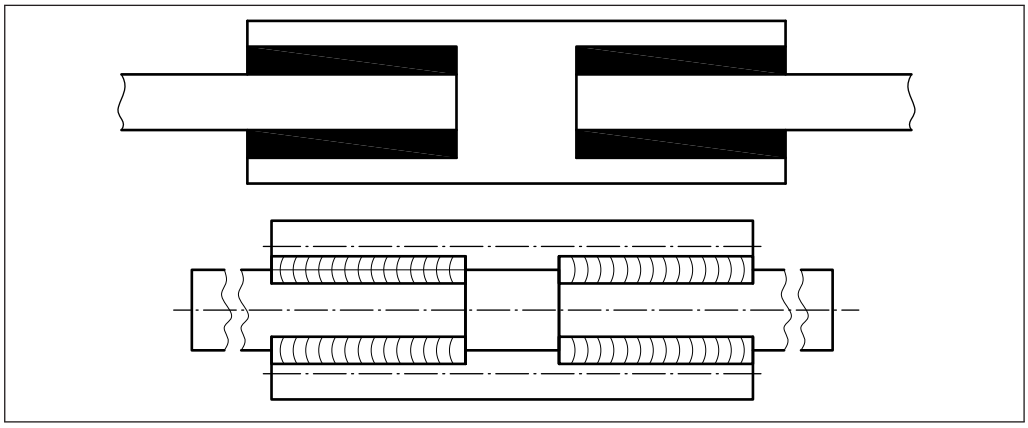
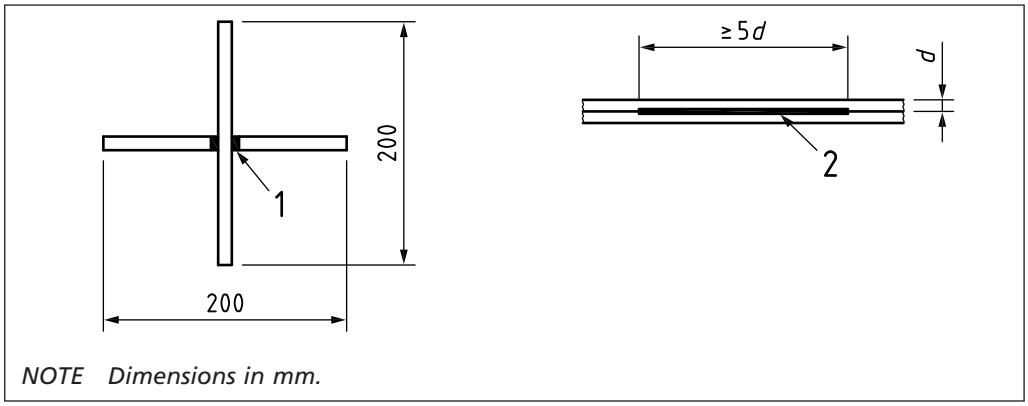


Figure D.4 **Test pieces for macro examination**



NOTE Dimensions in mm.

Annex E (normative) Examination and testing of test specimens

E.1 General

Test specimens should be welded in accordance with the relevant WPS.

All test pieces should be subject to a visual inspection prior to testing. Only test specimens that have met the recommendations of **7.4** for surface imperfections should be subject to further mechanical testing.

All mechanical tests should be conducted in accordance with BS EN ISO 15630-1 for tensile and bend tests and BS EN ISO 15630-2 for shear tests unless other guidance is given in Clause **7**.

E.2 Tensile test

E.2.1 Test specimen

The tensile test should be carried out on the as-welded test specimen and where practicable the location of the weld should be positioned approximately in the centre of the test specimen.

Test specimens should be prepared in accordance with Annex D.

Where a standard tensile test specimen cannot be prepared, for example between a bar and a steel section, the test specimen should be agreed between the responsible welding coordinator and the test laboratory. For test specimens consisting of bars joined to other steel components, care should be taken to ensure that the load bearing capacity of the steel component is equal to or greater than the nominal load bearing capacity of the joint being tested.

E.2.2 Test procedure

Where the test specimen configuration makes it impossible to perform a standard tensile test in accordance with BS EN ISO 15630-1, the testing procedure used should be agreed between the welding coordinator and the test laboratory.

E.2.3 Evaluation of results

The fracture surface of the weld should not contain any imperfections larger than the requirements of quality level B in accordance with BS EN ISO 5817.

The formula (E.1) may be used to evaluate the test results obtained.

$$F_m \geq A_n R_m \qquad (E.1)$$

where:

F_m is the maximum tensile force, in N;

A_n is the nominal cross-sectional area of the bar, in mm$^{2;}$

R_m is the nominal tensile strength of the reinforcing bar, in N/mm^2.

If R_m is not specified for the parent metal, the value of R_m should be taken as the specified characteristic yield strength R_e of the bar multiplied by the specified characteristic R_m/R_e ratio.

Other mechanical properties (e.g. A_{gt}), might be required and measured depending on the material standard being used or the product specification.

E.2.4 Reporting of results

The following should be reported as the results of the test:

a) the WPS used;

b) the type of test specimen and its dimensions;

c) the product standard requirements;

d) the location of the fracture;

e) the type and location of any imperfection on the fracture surface; and

f) the type and location of any imperfection identified during the visual inspection.

E.3 Shear test

E.3.1 Test specimen

The test specimen should be prepared in accordance with Annex D.

E.3.2 Test procedure

The test procedure should be in accordance with BS EN ISO 15630-2.

E.3.3 Evaluation of results

The shear force should meet the formula (E.2):

$$F_s \geq S_f A_s R_e \qquad (E.2)$$

where:

F_s is the shear force, in N;

S_f is the percentage shear factor of the nominal load bearing value;

A_s is the nominal cross-sectional area of the bar to be anchored, in mm^2;

R_e is the specified characteristic yield strength of the reinforcing steel bar, in N/mm^2.

The shear factor indicates the required strength of the joint as defined in the Project Specification.

E.3.4 Reporting of results

The following should be reported as the results of the test (as appropriate):

a) the WPS;

b) the type of test specimen and its dimensions;

c) the shear strength, in kN;

d) the location of the fracture;

e) the type and location of any imperfection on the fracture surface; and

f) the type and location of any imperfection identified during the visual inspection.

E.4 Bend test

E.4.1 Test specimen

The length of the test specimen should be in accordance with Annex D. The weld or the welded cross bar should be located approximately in the centre of the test specimen.

E.4.2 Test procedure

Test specimens should be bent on machines which impart a continuous bending action.

The bending machine formers should rotate freely and soft liners may be used to prevent crushing.

The test specimen should be bent through at least 60° during the bend test using a mandrel diameter in accordance with Table E.1.

Table E.1 **Mandrel diameters for bend test**

Diameter range for reinforcing steel bar	Diameter of mandrel in bend test
$D \leq$	5D
$8 < D \leq 12$	6D
$12 < D \leq 20$	8D
$20 < D \leq 32$	10D
$D > 32$	12D

E.4.3 Evaluation of results

The bent sample should be visually inspected. There should be no cracks visible to the naked eye on the surface of the bar. Partial detachment of the locational welds might occur along the surface of the bar if the bar material remains ductile.

E.4.4 Reporting of results

The following should be reported as the results of the test (as appropriate):

a) the WPS;

b) the type of test specimen and its dimensions;

c) the location of the fracture;

d) the type and location of any imperfection on the fracture surface; and

e) the type and location of any imperfection identified during the visual inspection.

E.5 Macro-examination test

The test specimen should be prepared and etched on one side in accordance with BS EN ISO 17639 to clearly reveal the fusion line, the heat affected zone and the build-up of the runs. The macro-examination should include unaffected parent metal.

The acceptance levels should be as stated in **7.4**.

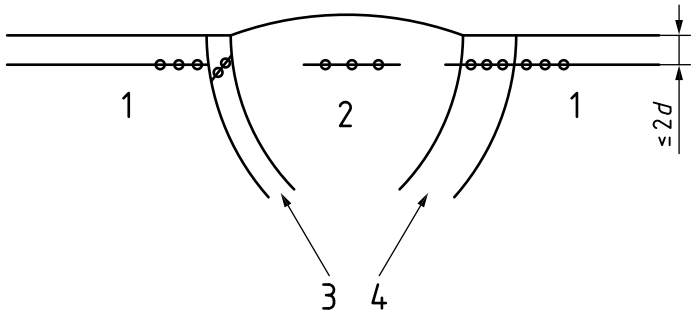
E.6 Hardness testing

The method of hardness testing should be in accordance with BS EN ISO 9015-1. The Vickers method HV_{10} should be used. The indentations should be made in the weld, the heat affected zones and the parent metal, with the purpose of measuring and recording the range of values in the weld joint. One complete row of indentations should be carried out at a maximum depth of 2 mm below the surface. There should be a minimum of three individual indentations in each part of the weld. For the heat affected zones, the first indentation should be placed as close to the fusion line as possible.

The acceptance levels should be as stated in **7.4**.

A typical example is shown in Figure E.1.

Figure E.1 **Example of hardness traverse**



Key

1 Parent material
2 Weld metal
3 Heat affected zone
4 Heat affected zone

NOTE Four is the preferred method of hardness measurement, although if the heat affected zone is narrow three can be used.

Annex F (informative) Guidance for the avoidance of hydrogen cracking in reinforcing steels and steel components joined to reinforcing steels

F.1 General

This Annex gives recommendations for the avoidance of hydrogen cracking, also commonly known as cold cracking.

Whilst it is recognized that there have been a number of different methods proposed for predicting preheat temperatures to avoid hydrogen cracking in non-alloyed, fine grained and low alloy steel weldments, the method proposed here is deemed to be the most suitable for practical use for reinforcing steels in accordance with BS 4449 and BS 4482.

If it can be demonstrated through procedure tests that the preheat temperatures can be reduced below those specified in this Annex without adversely affecting the quality of the weld then this may be allowed. Records of these tests should be fully documented.

NOTE It would be prudent to undertake a significant number of tests to ensure that preheat temperatures can be reduced and allow a safety margin for deviations in product analysis etc.

F.2 Method for the avoidance of hydrogen cracking in reinforcing steels

F.2.1 Parent metal

This clause covers all reinforcing steels produced in accordance with the chemical analysis limits of BS 4449 or BS 4482 as applicable.

The determination of safe, but economic, preheating levels for the prevention of hydrogen cracking is critically dependent on an accurate knowledge of the parent metal composition and C_{eq}, and on the weld metal composition. The C_{eq} for parent material is calculated using formula (F.1):

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \qquad (F.1)$$

where:

Mn is the percentage manganese content;

Cr is the percentage chromium content;

V is the percentage vanadium content;

Mo is the percentage molybdenum content;

Cu is the percentage copper content;

Ni is the percentage nickel content.

The values of individual elements and the value of the C_{eq} should not exceed the limits specified in BS 4449:2005+A3 Table 2. In addition, all other intentionally added elements, except those included within the C_{eq} formula, should be below the limit values specified in BS EN 10020:2000, Table1.

The maximum level of C_{eq} permitted in BS 4449 is 0.50%, and in BS 4482 it is 0.50% for grade 500.

BS 4449 and BS 4482 specify that all of the elements that are required to calculate the C_{eq} should be displayed on the test certificate. For other steel components, if, of the elements in this formula, only carbon and manganese are stated on the mill sheet for carbon and carbon-manganese steels, then 0.03 should be added to the calculated value to allow for residual elements. Where steels of different carbon equivalent or grade are being joined, the higher C_{eq} should be used.

NOTE Where there is doubt over the chemical analysis of the steel it is recommended that an actual analysis is undertaken.

F.2.2 Factors affecting cracking

The occurrence of hydrogen cracking depends on a number of factors: composition of the steel, the welding procedure, welding consumables and the stress involved. If the $t_{8/5}$ time (cooling time from 800 °C to 500 °C) associated with welding is too short, excessive hardening can occur in the heat affected zone. When the hydrogen in the weld is above the critical level the hardened zone can crack spontaneously under the influence of residual stress after the weld has cooled to near ambient temperature. Welding conditions can be selected to avoid cracking by ensuring that the heat affected zone cools sufficiently slowly, by control of weld run dimensions in relation to metal thickness, and if necessary, by applying preheat and controlling interpass temperature. Procedures for avoiding cracking, as well as selecting cooling times through the transformation temperature range to avoid hardened and susceptible microstructures, can involve controlling cooling in the lower part of the thermal cycle, typically 300 °C to 100 °C, thereby beneficially influencing the evolution of hydrogen from the weld joint.

The hydrogen content of the weld can be controlled by using hydrogen controlled welding processes and consumables and also, to some extent, by the application of post-heat in BS EN 1011-2.

Similar considerations apply to hydrogen cracking in the weld metal where, although hardening is on a reduced scale, actual hydrogen and stress levels are likely to be higher than in the heat affected zone. In general, welding procedures selected to avoid heat affected zone hydrogen cracking also avoid cracking in the weld metal. However, under some conditions such as high restraint, low C_{eq} steels, thick sections, or alloyed weld metal, weld metal hydrogen cracking can become the dominant mechanism.

The most effective assurance of avoiding hydrogen cracking is to reduce the hydrogen input to the weld metal from welding consumables. The benefits resulting from a growing number of possibilities where no preheat greater than 20 °C is required can be increased by using filler metals with lower hydrogen content.

Welding conditions for avoiding hydrogen cracking in carbon manganese steels have been drawn up in BS EN 1011-2:2001 Annex C and the guidance offered in this standard is recommended as good practice in the avoidance of hydrogen cracking.

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For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 1011-1, *Welding – Recommendations for welding of metallic materials – Part 1: General guidance for arc welding*

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Other publications

CARES Guide to Reinforcing Steel – Part 6: Welding of Reinforcing Steels, 2011.

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