BS 7191 : 1989

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British Standard Specification for

Weldable structural steels for fixed offshore structures

Aciers de construction soudables pour structures fixes en mer — Spécification

Schweißbare Baustähle für stationäre Bauten im küstennahen Bereich

Foreword

This British Standard has been prepared under the direction of the Iron and Steel Standards Policy Committee and specifies weldable structural steels for use in construction and in maintenance work for offshore structures.

The standard is adapted from BS 4360. It has been drafted in the form of a procurement specification and is intended to be used by the purchaser and others acting on his behalf to procure materials for offshore structures designed to operate in the European Sector. It specifies a more limited range of steel forms and grades than BS 4360 and provides for enhanced properties in some grades to reflect the needs of the European offshore industry. It also incorporates a number of options which the purchaser may invoke to meet demanding requirements in particular applications. The format and editorial style of BS 4360 has been utilized to the maximum extent possible.

The new grade designations, which are given in appendix H of BS 4360 : 1986, and which will be adopted in the next full revision of that standard have been used but with an amended form of sub-grade suffix.

Assessed capability. Users of this British Standard are advised to consider the desirability of assessment and registration of a supplier's quality systems against the appropriate Part of BS 5750 by a third party certification body.

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

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Section one. General

1 Scope

This British Standard specifies requirements for weldable structural steels to be used in the fabrication of fixed offshore structures in the form of plates, up to and including 150 mm thick, sections complying with BS 4848 : Parts 2, 4 and 5 and BS 4 : Part 1, and seamless tubulars up to and including 40 mm thick.

In the case of welded tubulars this standard covers only the requirements for parent material.

Minimum yield strengths up to 450 N/mm^2 are specified together with low-temperature impact properties at temperatures down to −40 °C.

The standard is applicable to offshore structures designed to operate in the European offshore sector but not to steel supplied for the fabrication of subsea pipelines, risers, process equipment, process piping, and other utilities. It is primarily applicable to the North Sea Sector, but may also be applicable in other areas provided that due consideration is given to local conditions, e.g. temperature.

This standard applies to material supplied ex-mill (see **12.1**) or from merchant's stock (see **12.2**).

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 6562 : Part 2 apply, together with the following.

2.1 parent product. The product rolled from one piece of steel.

2.2 manufacturer. The manufacturer of the steel products.

2.3 supplier. The manufacturer of material supplied ex-mill, either/or the merchant for material supplied from a merchant's stock (see clause **1**).

2.4 purchaser. The purchaser or his representative.

2.5 controlled rolling. A generic term for rolling procedures in which the temperatures and deformation during rolling are controlled to achieve desirable material properties.

2.6 thermo-mechanical controlled rolling (TMCR). A rolling procedure in which significant deformation takes place at temperatures below the normalizing range permitting little, if any, recrystallization of austenite and conferring beneficial properties on the material. The properties conferred by TMCR cannot be reproduced by subsequent normalizing or other heat treatments.

2.7 concast. Material produced by a continuous casting process route.

3 General

3.1 Grade designations

The new grade designations given in appendix H of BS 4360 : 1986 have been used but with amended sub-grade suffixes as follows.

Grade 275	Previous grade 43
Grade 355	Previous grade 50
Grade 450	Previous grade 55
Suffix D	Charpy V-notch test at −20 °C (as BS 4360)
Suffix E	Charpy V-notch test at −40 °C (as BS 4360)
Supplementary suffix M	Substantial modification to the nominally equivalent BS 4360 grade
Supplementary suffix Z	With specified through-thickness properties

This standard includes the following grades.

Grades with few changes from BS 4360	275D, 275E, 355D, 355E (minor changes to CEV and impact requirements only)
Grade as above but with through-thickness properties	275EZ
Grades substantially modified from BS 4360	355EM, 355EMZ, 450EM, 450EMZ

Appendix A gives a comparison between grades in this standard and those in appendix H of BS 4360 : 1986.

NOTE. Clauses in this standard are applicable to all grades except where specifically marked to indicate that they are applicable only to the substantially modified M or MZ grades.

3.2 Steel products

The steel products shall comply with the general requirements of this standard and with the specific requirements applicable to the grade concerned. Where any of the options given in appendix B are called up at the time of the enquiry and order, the steel products shall, in addition, comply with the requirements of these options.

4 Information to be supplied by the purchaser

4.1 General

The following information shall be supplied by the purchaser at the time of enquiry and order.

(a) Details of the product form, dimensions and quantity.

(b) The grade of steel (see tables 8 to 13).

(c) Whether use is for primary or secondary application.

4.2 Options

A number of options are specified in appendix B. In the event that the purchaser does not indicate his wish to implement any of these options and specify his requirements at the time of the enquiry and order, the supplier shall supply in accordance with the basic specification.

See also option **B.1**.

5 Steelmaking and manufacturing process

5.1 Process

5.1.1 *Grades 275D, 275E, 355D and 355E.* The steel shall be made by any process except the Bessemer process.

5.1.2 *Modified grades 355EM and 450EM.* The steel shall be made by the basic oxygen or basic electric arc furnace process. All steel shall be fully killed and made to fine grain practice.

5.1.3 *Z grades 275EZ, 355EMZ and 450EMZ.* The steel shall be made by a low sulphur and phosphorus refining process in a basic oxygen or basic electric arc furnace. All steels shall be fully killed and made to a fine grain practice. The steel for these grades shall be vacuum degassed or ladle refined.

5.2 Rimming steel

Rimming steel shall not be supplied.

5.3 Limits and segregation control for concast modified grades

5.3.1 Provided that the resultant products comply with all the relevant requirements of this standard, the maximum thickness limit for the use of the continuous casting process shall be at the manufacturer's discretion.

See also option **B.2**.

5.3.2 The minimum rolling reduction ratio of concast material for plate shall be 4 : 1.

See also option **B.3**.

5.3.3 Slab produced by the continuous casting route shall be examined for centreline segregation. The frequency of testing shall be once per strand per four casts.

NOTE. No acceptance levels are specified and the manufacturer should agree with the purchaser, at the time of the enquiry and order, the position of testing and the acceptance values for sulphur printing, macro-etching or alternative methods of checking segregation.

5.4 Plate forming procedures for modified grades

Plate forming procedures shall not be supplied.

See also options **B.4** and **B.5**.

6 Supply condition (see also option B.6)

6.1 Plates of grades 275 and 355 shall be supplied in the normalized condition.

6.2 Plates of grade 450 shall be roller quenched and tempered.

See also option **B.7**.

6.3 Sections of grades 275 and 355 over 25 mm thick shall be normalized.

6.4 Seamless tubulars over 12.7 mm wall thickness shall be supplied in the normalized condition except for grade 450 which shall be supplied quenched and tempered.

7 Chemical composition and mechanical properties (see also option B.8)

7.1 Ladle analysis

7.1.1 *General.* The chemical composition of the steel shall be determined by ladle analysis and shall be as given in tables 8, 10 and 12.

The manufacturer shall supply details of the ladle analysis to the purchaser and this shall be an average based on at least three samples per cast.

7.1.2 *Residual element control for modified grades 355EM, 355EMZ, 450EM, 450EMZ.* Boron (B) shall not be intentionally added to the steel nor shall vanadium (V) for plate of grades other than 450EM and 450EMZ. Elements other than those listed in tables 8, 10 and 12 shall not be intentionally added. Calcium treatment shall not be used without the permission of the purchaser, except where required for the purposes of desulphurization (see calcium limits given in tables 8, 10 and 12).

7.2 Product analysis

The product analysis shall comply with the limits given in tables 8, 10 and 12 and, in the case of modified grades, shall also be within the ranges proposed by the manufacturer (see **7.3**).

See also option **B.8**.

Product analysis shall be determined twice per cast or once per 40 t, or part thereof, whichever is more stringent. The product analysis shall be determined on the test sample used for the verification of the mechanical properties (see section three).

In the event of dispute, compliance with this standard shall be decided on the basis of an independent analysis using the methods described in BS 6200 : Part 3 or BSI Handbook No. 19, whichever is applicable.

7.3 Carbon equivalent value (CEV)

The steel shall have a maximum CEV, as given in table 1, based on product analysis and calculated using the following equation:

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

7.4 Mechanical properties

Mechanical properties shall be as given in table 9 for plates, table 11 for sections and table 13 for seamless tubulars.

NOTE. Individual manufacturers are able to supply steels with specified minimum yield strengths slightly above those specified in tables 9, 11 and 13. Advantage may be taken of such higher values if the manufacturer can supply sufficient property data. If this approach is adopted, all property values may be agreed separately with the purchaser.

8 Weldability data for modified grades

NOTE 1. Weldability data are only required for plates exceeding 40 mm in thickness and for rolled sections and seamless tubulars over 25 mm in thickness.

At the time of the enquiry/order the manufacturer shall have available data on the weldability of his material. Any previously obtained data which the manufacturer proposes to submit shall have been verified by a competent third party, acceptable to the purchaser and who witnessed the tests. All previously obtained data presented shall bear the manufacturer's stamp or seal.

NOTE 2. These data refer only to the weldability of the material being supplied and are intended for use in development and preparation of fabrication procedures. If these data are unacceptable to the purchaser he should consider option **B.9**.

9 Quality of finished steel

9.1 Plates

9.1.1 *Surface condition.* All surfaces shall be 100 % visually inspected. The surface condition shall comply with BS 6512 except as otherwise specified in this clause. Plates shall be presented for inspection such that the steel surface can be readily examined.

Weld repair by the manufacturer or supplier shall not be carried out.

The manufacturer may correct minor surface defects by grinding, but the area limitations given in **5.2.2.3** of BS 6512 : 1984 shall apply.

Where defects are classified as type E in accordance with BS 6512, repair shall be followed by magnetic particle inspection or dye penetrant inspection.

9.1.2 *Internal soundness for grades other than modified grades.* For grades other than modified grades, plates shall be deemed to comply with the internal soundness of grade LC1 of BS 5996.

NOTE. Unless specified by the purchaser at the time of ordering, there is no obligation on the supplier to carry out ultrasonic testing. Option **B.10** should be called up when ultrasonic testing is required to be undertaken by the supplier.

9.1.3 *Internal soundness for modified grades.* The internal soundness of all plates shall be verified by ultrasonic testing in accordance with BS 5996 and shall comply with grade L4 of BS 5996 for MZ grades and grade LC3 of BS 5996 for M grades. Ultrasonic testing shall be carried out in the final heat-treatment condition and with a probe frequency of 4 MHz.

Table 1. Maximum product CEV for plates, sections and seamless tubulars

Grade	Maximum CEV	Thickness
	%	mm
275D	0.41	Up to and including 20
275E 275EZ	0.39	Up to and including 40
355D	0.43	Up to and including 20
355E	0.43	Up to and including 40
355EM 355EMZ	0.43	Up to and including 40
	0.44	Over 40 up to and including 75
	0.45	Over 75 up to and including 150
450EM 450EMZ	0.43	Up to and including 75

9.2 Sections

9.2.1 *Defects.* All surfaces shall be 100 % visually inspected for defects. The material shall be sound and free from such internal and external defects or surface flaws as might preclude its use for the purpose for which it is intended.

9.2.2 *Correction of minor defects.* The manufacturer may remove minor surface defects by grinding but, in all cases, the thickness shall not be reduced locally by more than 3 mm and the final thickness shall not be more than 4 % below the minimum otherwise allowed by BS 4 : Part 1 and BS 4848 : Parts 4 and 5.

The total rectified area shall not exceed 50 000 mm^2 in any one square metre (5 %) without specific approval of the purchaser.

9.2.3 *Repair by welding.* Weld repair shall only be carried out with specific approval of the purchaser.

Where weld repairs are carried out, the defects shall be removed by grinding or chipping followed by magnetic particle inspection and then by welding subject to the following conditions.

(a) After complete removal of the defect and before welding, the thickness shall not have been reduced to less than 80 % of its nominal dimensions.

(b) The welding shall be carried out in accordance with BS 5135 by operators approved to BS 4871 : Part 1. The weld shall be ground smooth and flush with the adjacent surface of the product and subjected to non-destructive testing as specified by the purchaser. The manufacturer shall follow documented welding procedures established in accordance with BS 4870 : Part 1 and approved by the purchaser which are appropriate for the material being welded.

9.2.4 *Internal soundness for modified grades.* Rolled sections with a web thickness greater than 12 mm shall be subject to ultrasonic examination of webs and flanges when specified by the purchaser and shall meet the requirements of grade L3 of BS 5996.

NOTE. Testing of the region between the web and the flange should be subject to agreement between the supplier and the purchaser.

9.3 Seamless tubulars

9.3.1 Seamless tubulars shall be clean and free from such defects as can be established by visual inspection.

Visual inspection shall include the inside surface where practicable.

9.3.2 Surface marks and imperfections such as scabs, seams, tears, laps, slivers or gouges may be dressed by grinding and machining provided that the thickness of the seamless tube, after dressing, does not fall below the nominal thickness by more than the tolerance specified in **16.2.**

Magnetic particle inspection shall be used to confirm removal of the defect.

9.3.3 All dressed areas shall blend smoothly into the contour of the seamless tube.

9.3.4 Seamless tubulars shall contain no dents greater than 3 mm or 1 % of the outside diameter, whichever is the lesser, when measured as the gap between the lowest point of the dent and a prolongation of the original contour of the seamless tubular. The length of the dent in any direction shall not exceed 25 % of the seamless tubular outside diameter.

All cold formed dents with a sharp bottom gouge shall be considered a defect and the gouge shall be removed by grinding.

9.3.5 All seamless tubulars shall be ultrasonically examined over the full length for laminar defects. The size of laminations shall be determined by manual ultrasonic examination and any seamless tubular containing a lamination exceeding 1000 mm^2 in area shall be deemed not to comply with this British Standard.

9.3.6 Ultrasonic testing of seamless tubulars shall be carried out for longitudinal defects and shall meet the supplementary requirements of API 5L except that the depth of the reference notch shall be 5 % of the thickness.

9.4 Ultrasonic, magnetic particle and dye penetrant inspection procedures

For implementation of non-destructive testing procedures and evaluation, all personnel shall be qualified to CSWIP level 3.1.P to 3.4.P (CSWIP-UST-5), or equivalent as appropriate. Magnetic particle inspection personnel shall be qualified to CSWIP-MAGPEN 4 or equivalent.

Where applicable ultrasonic testing shall be carried out in accordance with BS 5996, magnetic particle inspection (MPI) shall be carried out in accordance with BS 6072. The manufacturer shall submit written ultrasonic and magnetic particle inspection (MPI) and dye penetrant inspection procedures for approval prior to production of the order. These procedures shall include details of the following:

(a) equipment to be used;

(b) calibration standards;

(c) frequency of calibration;

(d) maintenance programmes;

(e) operator qualifications;

(f) reporting procedures;

(g) frequency and size of probes (ultrasonic testing);

(h) measurement of field strength (MPI);

(i) maximum ultrasonic scanning speed.

See also option **B.11.**

10 Identification of cast

The manufacturer shall identify the ingots, billets, slabs, plates, steel sections and seamless tubulars, etc., in such a way as to enable the finished steel to be traced to the cast from which it was made.

11 Marking

11.1 Die stamping and paint marking

11.1.1 *General.* Die stamp digits shall be produced by round-nosed dies, shall be at least 8 mm high and shall be ringed with white paint for ease of identification. They shall be stamped on plates so that the letters are aligned at 90 ° to the principal direction of rolling. Paint marking shall be in white with digits at least 40 mm high.

All markings shall be located in accordance with figures 1 to 3.

The following information shall be die stamped:

(a) cast number;

(b) if practicable, the supplier's plate/section/seamless tubular number;

NOTE. This may not be possible at some section mills. This will be highlighted by the supplier at the time of the enquiry and order.

(c) type of steel and grade;

(d) manufacturer's brand mark;

(e) certifying authority stamp (where appropriate).

The following information shall be paint marked:

(f) purchase order number;

(g) item size (thickness, width, length, section identification, diameter and wall thickness, etc.);

(h) material grade;

(i) principal rolling direction for plates (arrow);

(j) purchaser's unique identification number (where applicable).

11.1.2 *Bundling.* For sections, bundling may be carried out for sizes 203 mm and below, but shall be restricted to material from one cast. Where sections are to be used for primary applications each individual section within a bundle shall be identified. When a bundle is split for re-distribution the relevant identification marks, in accordance with items (a) to (e), shall be transferred to the reconstructed bundles or to the individual items as appropriate.

11.2 Colour coding

Each plate shall be painted with either one or two 50 mm wide diagonal bands, depending on the grade, extending over the edges in accordance with figure 1.

Each section shall be painted with either one or two 50 mm wide bands, depending on the grade, along the longitudinal axis of the section and extending over the edges in accordance with figure 2.

NOTE. In the case of bundled sections it is sufficient to add splashes of paint to the ends of the bundles only.

See also option **B.12**.

Each seamless tubular shall be painted with either one or two 50 mm wide bands, depending on the grade, longitudinally along the external surface and extending over the edges as shown in figure 3.

See also option **B.12**.

Where two bands of the same colour are required they shall be separated by a minimum distance of 25 mm. The number and colour of bands shall be as follows:

grade 450EMZ	green	green
grade 450EM	green	—
grade 355EMZ	blue	blue
grade 355EM	blue	—
grade 355E	blue	white
grade 355D	blue	yellow
grade 275EZ	red	red
grade 275E	red	—
grade 275D	unpainted	—

All paint for colour coding and stencil marking shall be applied to a clean, dry, oil-free surface and shall be able to resist weathering for at least 6 months and shall be commercially free from cadmium, lead, zinc, copper and tin.

The colour used for colour coding and marking shall be in accordance with the appropriate references of BS 5252, as summarized below:

blue	20E51
green	12D45
white	00E55
red	04E53
yellow	10E53

11.3 Protective coatings

All materials shall be supplied without the addition of protective surface coatings.

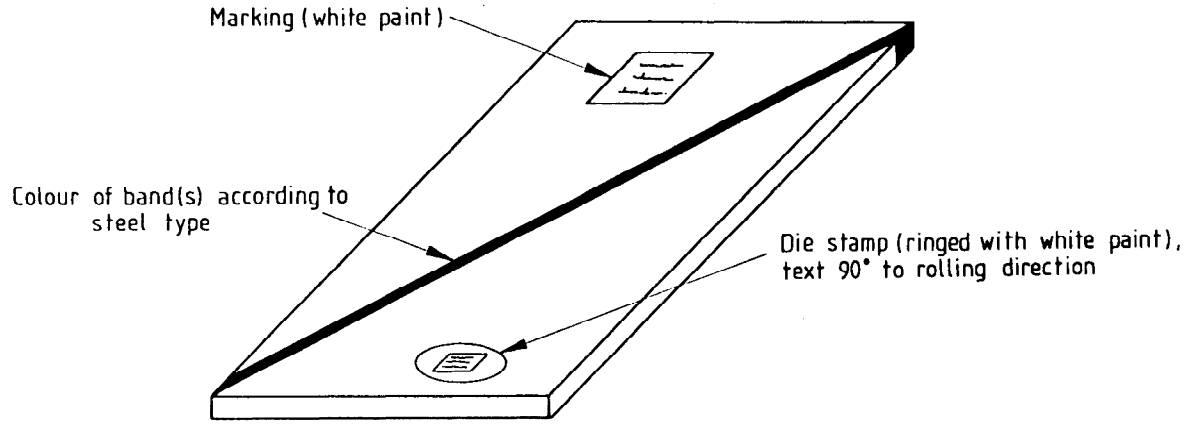


Figure 1. Plates: marking, die stamping and colour coding (see clause **11**)

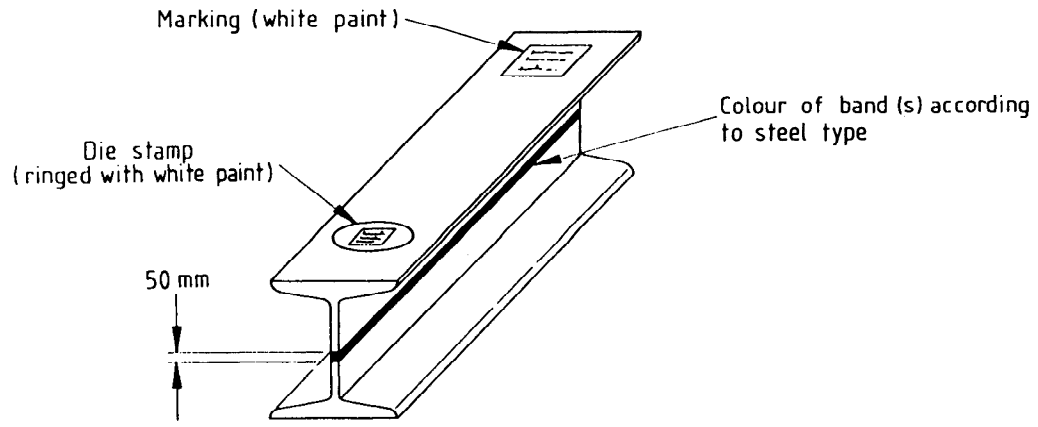
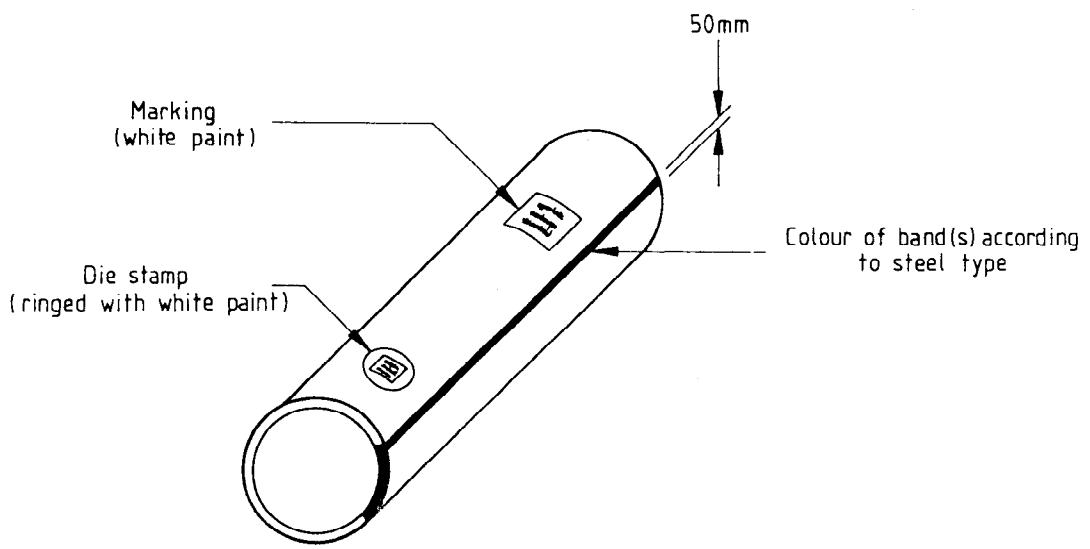


Figure 2. Rolled sections: marking, die stamping and colour coding (see clause **11**)



12 Test certificates

12.1 Ex-mill supply

One original of all relevant certificates and reports, clearly legible and in the English language shall be submitted to the purchaser at the time of despatch.

See also option **B.13.**

SI units shall be used on all documentation.

The mill certificates shall comply with DIN 50049 (3.1.B) and shall be acceptable to the certifying authority. They shall contain at least the following information.

(a) *Identification,* as follows:

(1) mill location;

(2) the purchaser's order and item number;

(3) method of steel manufacture;

(4) heat or cast number;

(5) bar, bloom or plate number;

(6) supply condition;

(7) dimensions;

(8) grade of steel.

(b) *Composition,* as follows:

(1) ladle analysis;

(2) product analysis;

(3) carbon equivalent.

(c) *Heat treatment,* including details of heat treatment stating temperature, soaking times and cooling method;

NOTE. Records should be available at the mill for a period to be agreed with the purchaser.

(d) *Mechanical properties,* as follows:

(1) yield strength, tensile strength, yield strength/tensile strength ratio, elongation;

(2) Charpy V-notch impact test results;

(3) through thickness properties (if required);

(4) strain age test results (if required).

(e) *Nominal mass.*

(f) *Non-destructive test (NDT) results,* as follows:

(1) verification of results of NDT are to be included on the test certificate;

(2) the manufacturer's own results of NDT are to be endorsed by an operator approved under CSWIP-UST-5 or equivalent;

(3) details of segregation control monitoring are to be given in a separate report.

In addition to items (a) to (f), the analysis of residual elements and the results of any additional testing deemed necessary by the purchaser shall be submitted in the form of separate reports.

12.2 Merchant supply

If any steel is supplied from a merchant's stock, the merchant shall be responsible for the following.

(a) Supplying to the purchaser a copy of the original order requirements placed on the mill and the subsequent sales history of the product.

(b) Supplying to the purchaser all documentation required by this standard including an original copy of the mill certificate (see **12.1**) or a copy verified by the certification authority.

(c) Satisfying the purchaser by means of numbers or identification marks on the steel (or tab when parcels of steel are bundled) that such steel has been tested and complies with this standard, as applicable to the material specified, particularly where the dimensions or condition of the steel have been altered.

13 Delivery

At least 1 week prior to the start of delivery the supplier shall confirm with the purchaser the place for delivery of the steel.

Steel shall be delivered together with an accompanying advice note which shall contain the following minimum information:

(a) mill location;

(b) the purchaser's purchase order and item number;

(c) cast number;

(d) test/plate number;

(e) the plate/seamless tubular/section sizes;

(f) the material grade.

14 Mass of steel

The mass of plates, sections or seamless tubulars shall be calculated on the basis that the steel has a density of 7850 kg/m^3.

Section two. Specific requirements for dimensional and shape tolerances

15 Tolerances for plates

15.1 General

Tolerances for plates produced on continuous mills shall comply with BS 1449 : Part 1.

Tolerances for plates produced on non-continuous mills shall comply with **15.2** to **15.6**.

15.2 Length tolerances for plates

The length tolerances on ordered length for plates shall be as given in table 2. The length of a plate shall be taken as the length of the largest rectangle contained within the plate.

See also option **B.14**.

Table 2. Length tolerances for plates

Ordered length	Tolerances
mm	mm
Less than 4 000	−0 +20
4 000 to less than 6 000	−0 +30
6 000 to less than 8 000	−0 +40
8 000 to less than 10 000	−0 +50
10 000 to less than 15 000	−0 +70
15 000 up to and including 20 000	−0 +100

15.3 Width tolerances for plates

The width tolerances on ordered width for plates shall be as given in table 3. Width shall be measured perpendicular to the major axis of the plate.

See also option **B.14**.

Table 3. Width tolerances for plates

Ordered width	Tolerances
mm	mm
600 to less than 2 000	−0 +20
2 000 to less than 3 000	−0 +25
3 000 up to and including 4 000	−0 +30

15.4 Thickness tolerances

The thickness tolerances on ordered thickness of plates shall be as given in table 4. Thickness shall be measured at any point more than 15 mm from the edges of the plate.

See also options **B.15** and **B.16**.

15.5 Edge camber for plates

Edge camber shall be limited so that it shall be possible to inscribe the dimensions of the ordered plate within the delivered size. The edge camber, C, shall be taken as the maximum deviation between one longitudinal edge and the straight line joining the two ends of this edge (see figure 4).

15.6 Flatness tolerances for plates

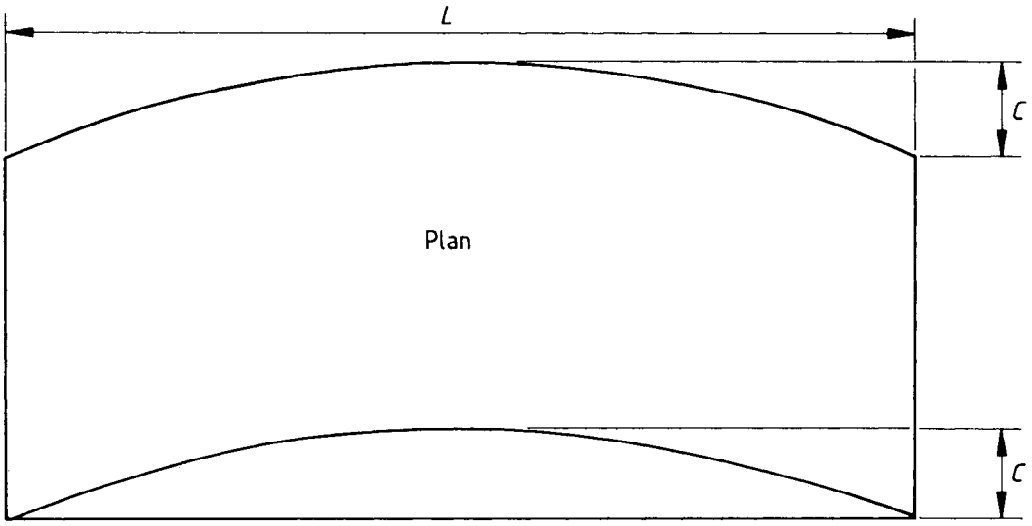
The flatness tolerances for plates shall not exceed the normal flatness tolerances given in table 5 for the straightedge selected except that, for thicknesses of 50 mm and over, the flatness tolerance shall be based on a straightedge length of 2000 mm for all directions.

To measure flatness, the plate resting under its own weight shall be placed on a flat horizontal surface. Deviations with respect to flatness shall be determined by measuring the distance between the plate and a straightedge resting on the plate, the straightedge being placed in any direction.

Table 4. Thickness tolerances for plates

Ordered thickness	Width of plate (in mm)				
	Up to and including 2 000	Over 2 000 up to and including 2 500	Over 2 500 up to and including 3 000	Over 3 000 up to and including 3 500	Over 3 500 up to and including 4 000
mm	mm	mm	mm	mm	mm
Less than 5	± 0.40	± 0.50	± 0.50	—	—
5 to less than 8	± 0.45	± 0.60	± 0.80	± 0.80	—
8 to less than 25	± 0.55	± 0.65	± 0.80	± 0.85	± 0.95
25 to less than 40	± 0.55	± 0.70	± 0.80	± 0.85	± 0.95
40 to less than 80	± 0.60	± 0.80	± 0.85	± 0.95	± 1.05
80 up to and including 150	± 1.10	± 1.15	± 1.20	± 1.25	± 1.25

Only the portion situated between the two points of contact shall be taken into consideration. Deviations shall be measured at a point a minimum of 20 mm from the longitudinal edges and a minimum of 100 mm from transverse edges. When distances between points of contact are between 500 mm and 1000 mm, the deviation shall be obtained by taking the distance between points of contact and calculating proportionally from the deviation given for a 1000 mm straight edge in table 5.



L is the length of plate
C is the edge camber

Figure 4. Edge camber of plates (see **15.5**)

Table 5. Normal flatness tolerances for plates

Ordered thickness	Straightedge length selected	Permitted deviations for ordered widths (in mm)							
		Less than 1 500	1 500 to less than 2 000	2 000 to less than 2 500	2 500 to less than 2 750	2 750 to less than 3 000	3 000 to less than 3 250	3 250 to less than 3 500	3 500 to less than 4 000
mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
3 to less than 4	1000	7	8	10	–	–	–	–	–
	2000	14	18	22	–	–	–	–	–
4 to less than 6	1000	7	7	8	10	–	–	–	–
	2000	14	16	21	25	–	–	–	–
6 to less than 8	1000	7	7	8	8	8	–	–	–
	2000	14	14	16	17	20	–	–	–
8 to less than 10	1000	7	7	7	7	8	8	9	–
	2000	13	13	14	15	16	18	20	–
10 to less than 20	1000	7	7	7	7	7	8	8	9
	2000	12	12	12	13	14	15	17	19
20 to less than 50	1000	7	7	7	7	7	8	8	9
	2000	11	11	12	12	12	13	14	16
50 up to and	2000	10	10	10	10	10	10	10	10

For ripples/corrugations less than 2 m apart (peak to peak) the following criteria shall apply.

(a) The maximum depth of any ripple/corrugation under the 2 m straight edge shall be 5 mm. The average depth of all ripples on any one plate shall not exceed 4 mm.

(b) The minimum depth to constitute a ripple/corrugation shall be 2 mm.

(c) The maximum number of ripples/corrugations allowed in any one plate shall be as given in tables 6 and 7, and shall apply to all plates 10 mm thick and over and for all plate widths.

Table 6. Maximum number of ripples/corrugations in plate with thickness ⩾ 12 mm

Length	Maximum number of ripples/corrugations
m	
6	2
9	3
12	4
15	5

Table 7. Maximum number of ripples/corrugations in plate with thickness ⩾ 10 mm < 12 mm

Length	Maximum number of ripples/corrugations
m	
⩽ 6	4
⩽ 9	5
⩽ 12	6
⩽ 15	8

(d) The flatness tolerance shall, in all cases, be measured to the upper surface of the plate laid on a level surface.

See also option **B.17**.

16 Tolerances for sections and seamless tubulars

16.1 Sections

Rolling tolerances for sections shall comply with BS 4 : Part 1 and BS 4848 : Part 2.

Tolerances on specific lengths shall be $^{0}_{+50}$ mm. The same tolerance shall still apply if the product is supplied in the normalized condition.

16.2 Seamless tubulars

The size, mass, length and straightness tolerances shall be as specified in BS 4848 : Part 2 and shall also apply if the product is heat treated. Ends of seamless tubulars shall be supplied square cut. Additionally, the tolerance on wall thickness shall be $^{+15}_{-12.5}$ %.

Seamless tubulars shall be supplied in the lengths defined in the purchase order with the above tolerances. Jointers shall not be supplied.

Diameter and roundness shall be based on the nominal internal diameter, i.e. the specified outside diameter minus twice the nominal wall thickness. For a distance of 100 mm at both ends the internal diameter shall not deviate from the nominal internal diameter by more than ± 0.5 %.

Section three. Specific requirements for testing

17 Selection and identification of test samples for tensile and impact tests

17.1 Selection of samples

The manufactuter shall randomly select and identify test samples in accordance with clauses **18**, **19**, **22** and **23**.

See also options **B.18**, **B.19**, **B.20** and **B.21**.

17.2 Condition of samples

17.2.1 *General.* The test samples shall be in the heat-treatment condition specified in clause **6**.

17.2.2 *Modified grades*

17.2.2.1 *Grades 355EM and 355EMZ.* For plates and seamless tubulars of thicknesses over 20 mm and piling of thicknesses over 65 mm, the test samples shall be subjected to a simulated post-weld heat-treatment (PWHT), at a nominal temperature of 600 ± 20 °C, for a minimum time of either 1 h per 25 mm thickness of plate, or 4 h, whichever is the greater. The test samples shall then comply with the minimum yield strength, tensile strength and impact properties given in tables 9 and 13.

See also option **B.22**.

17.2.2.2 *Grades 450EM and 450EMZ.* For plates and seamless tubulars of thickness over 20 mm, the test samples shall be subjected to a simulated post-weld heat-treatment, within the temperature range 550 °C to 620 °C with a maximum temperature of 25 °C below the tempering range on the test certificate. The heat-treatment shall last for either 1 h per 25 mm thickness, or 4 h, whichever is the greater. The test samples shall then comply with the minimum yield strength, tensile strength and impact properties given in table 9 and table 13.

18 Number of tensile tests

One tensile test shall be made on the finished steel for each 40 t or part thereof of the same thickness range (see tables 9, 11 and 13), from the same cast, showing a thickness variation of not more than 5 mm above and below the thickness of the product sampled except that where ingot practice is used, one tensile test shall be made on each parent product.

19 Direction and position of tensile test samples

19.1 Direction of samples

19.1.1 *Plates.* Tensile test samples shall be cut with the longitudinal axis of the test samples transverse to the principal direction of rolling.

19.1.2 *Sections and seamless tubulars.* Tensile test samples shall be cut with the longitudinal axis of the test samples parallel to the principal direction of rolling.

19.2 Position of samples

19.2.1 *Plates.* Samples shall be taken from one end midway between the centre and one edge (see appendices C and D).

19.2.2 *Sections.* Samples shall be taken from the relevant flange positions shown in appendix C.

NOTE. In the case of sections with tapered flanges, the samples may be taken from the web or flange, at the manufacturer's discretion, as shown in appendix C.

19.2.3 *Seamless tubulars.* Samples may be taken from any location in the seamless tubular.

20 Tensile test pieces

20.1 Preparation of test pieces

Tensile test pieces shall be prepared in accordance with BS 18 from the test samples obtained in accordance with clauses **17** and **19** so that, wherever practicable, the rolled surface of the steel is retained on two opposite sides of the test piece. Where this is not practicable, round or rectangular test pieces having a diameter or thickness of not less than 12.5 mm shall be taken from the relevant position shown in appendix D.

20.2 Straightening of test pieces

Any straighening of test pieces which is required shall be done cold. Test pieces cut from seamless tubulars shall be tested in the curved condition, but the ends may be flattened cold for gripping.

21 Tensile test

21.1 General

The tensile test shall be carried out in accordance with BS 18. The tensile strength, R_m, the yield strength, R_e, and the elongation, A, shall be determined and the results obtained shall comply with the values given in tables 9, 11 and 13 for the appropriate grade.

NOTE. For the yield strength, the manufacturer may determine the upper yield stress, R_{eH}, or the 0.5 % proof stress (total extension), $R_{t0.5}$.

21.2 Dispute

If the result is in doubt or dispute, the yield strength shall be deemed not to be reached until the total extension under load, as determined by extensometer or dividers, is observed to be 0.5 % of the gauge length, i.e. 0.5 % proof stress (total extension), $R_{t0.5}$.

21.3 Elongation

Elongation shall be as given in tables 9, 11 and 13 and relates to an 80 mm gauge or 200 mm gauge length or a proportional gauge length of $5.65\sqrt{S_o}$, where S_o is the original cross-sectional area of the test piece.

If other gauge lengths are used, the corresponding elongation on a gauge length of 80 mm or 200 mm or $5.65\sqrt{S_o}$

22 Number of impact tests

22.1 Plates

22.1.1 *General.* For steel grades 275D, 275E, 275EZ, 355 D and 355E, the test shall be made on three adjacent Charpy V-notch test pieces taken from one of the thickest plates of each 40 t or part thereof of the same thickness range (see table 9) from the same cast.

22.1.2 *Modified grades.* For steel grades 355EM, 355EMZ, 450EM and 450EMZ, the test shall be made on three adjacent Charpy V-notch test pieces taken from each parent product.

22.2 Seamless tubulars and sections

22.2.1 For steel grades 275D and 355D, the test shall be made on three adjacent Charpy V-notch test pieces taken from one of the thickest products of each 40 t or part thereof of the same thickness range (see tables 11 and 13) from the same cast.

22.2.2 For steel grades 275E, 275EZ, 355EM, 355EMZ and 450EM, the test shall be made on three adjacent Charpy V-notch test pieces taken from one of the thickest products for every 5 t or from each parent product if its mass exceeds 5 t.

23 Position of impact test samples

The impact test samples for plates and seamless tubulars shall be taken from positions as shown in appendix E. For sections the impact test samples shall be taken from within 25 mm of the centres of the positions shown in appendix E. For sections of non-uniform thickness longitudinal impact test samples shall be taken from the thickest part of the section at the locations shown in appendix E.

24 Impact test pieces

NOTE. Impact tests for material less than 6 mm are not normally carried out but may be agreed between the purchaser and the manufacturer at the time of the enquiry and order.

24.1 General

The test pieces shall be cut parallel or transverse to the principal direction of rolling as appropriate (see **24.5** and **24.6**), and the axis of the notch shall be perpendicular to the rolled surface of the product (see figure 5). The test pieces shall be prepared in accordance with BS 131 : Part 2 and **24.2** to **24.4** of this standard.

24.2 Material 20 mm thick and over

For material of thicknesses of 20 mm and over, standard 10 mm x 10 mm test pieces shall be machined so that they do not include material nearer to the surface than 3 mm.

24.3 Material equal to or greater than 12 mm thick up to but excluding 20 mm

For material equal to or greater than 12 mm thick and up to but excluding 20 mm thick, standard 10 mm x 10 mm test pieces shall be machined so that they do not include material nearer to the surface than 1 mm.

24.4 Material equal to or greater than 6 mm thick but less than 12 mm thick

For material equal to or greater than 6 mm thick and up to but not including 12 mm thick, one of the following sizes of test pieces shall be prepared using the full thickness where necessary:

(a) standard test piece, 10 mm x 10 mm;

(b) subsidiary standard test piece, 10 mm x 7.5 mm;

(c) subsidiary standard test piece, 10 mm x 5 mm.

24.5 Plates of general and modified grades

The test pieces shall be taken from the following positions:

(a) the sub-surface, as specified in **24.2** and **24.4** for all grades;

(b) mid-thickness, when the thickness is above 40 mm for modified grades only.

Charpy V-notch test pieces shall be cut parallel to the principal direction of rolling for grades 275D, 275E, 275EZ, 355D and 355E and transverse to the principal direction of rolling for grades 355EM, 355EMZ, 450EM and 450EMZ (see figure 5).

24.6 Sections and seamless tubulars

Charpy V-notch test pieces shall be cut parallel to the principal forming direction for all grades.

25 Impact tests

25.1 Method of testing

The impact test shall be carried out in accordance with BS 131 : Part 2 at the temperature given in tables 9, 11 and 13 for the grade ordered. For piling material the impact tests at mid-thickness shall be carried out at -30 °C instead of -40 °C.

25.2 Values for standard test pieces

The average impact value obtained from three standard 10 mm x 10 mm test pieces shall be not less than the appropriate value given in tables 9, 11 and 13 for the grade ordered (see also **25.4**).

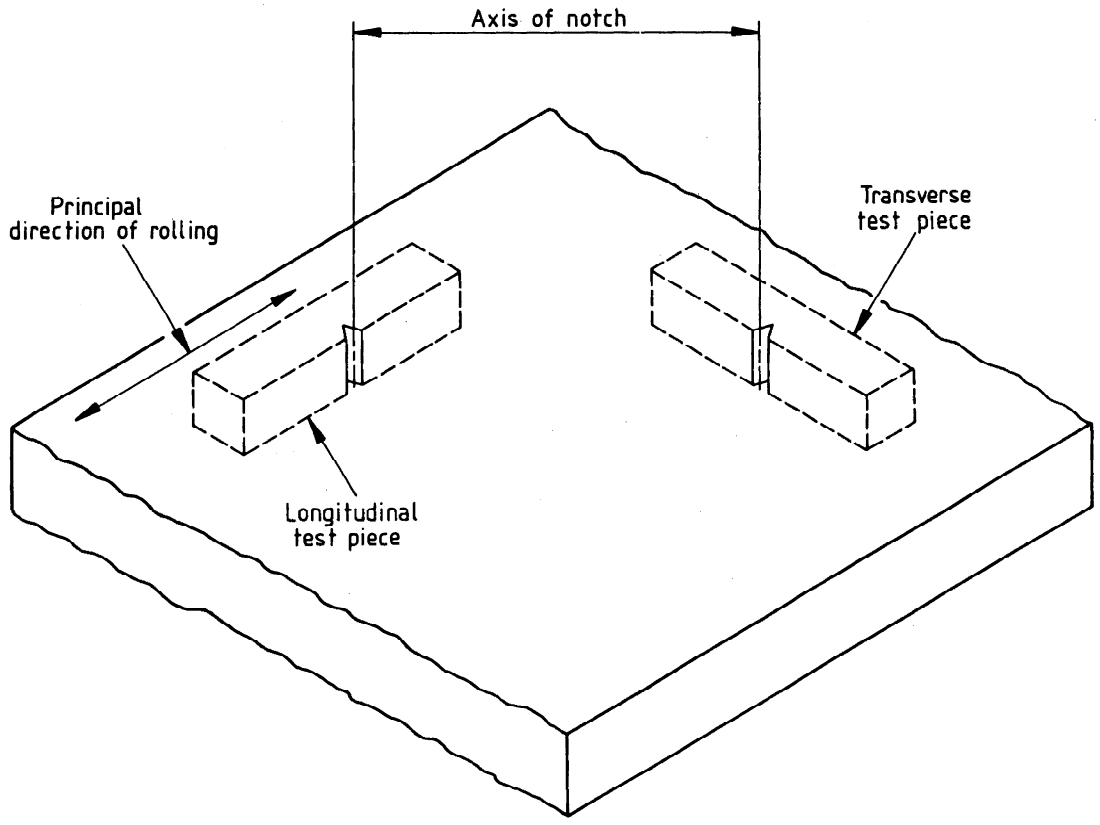


Figure 5. Location of impact test pieces

25.3 Values for subsidiary standard test pieces

The average impact values (see also **25.4**) obtained from three subsidiary standard test pieces shall be as follows:

(a) for 10 mm x 7.5 mm test pieces, 80 % of that specified in **25.2** for standard 10 mm x 10 mm test pieces; and

(b) for 10 mm x 5 mm test pieces, 70 % of that specified in **25.2** for 10 mm x 10 mm test pieces.

25.4 Individual value

For standard and subsidiary standard test pieces one individual value may be below the average values specified in **25.2** and **25.3** but, if so, it shall be not less than 70 % of that value.

25.5 Strain-age tests for modified grades

Strain-age tests for modified grades shall not be carried out.

NOTE. DOE Guidance Note 'Offshore Installations: Guidance on design and construction' recommends that strain-age tests should be carried out on steel formed with a strain greater than 5 %.

See also option **B.23**.

26 Through-thickness testing for Z grades

Through-thickness testing for Z grades shall not be carried out.

See also option **B.24**.

27 Retests

27.1 Tensile tests

Should a test result not comply with clause **21**, two further test pieces shall be made on samples taken from the product from which the original test piece was prepared.

NOTE. In the case of sections with tapered flanges, the retests may be made on test pieces taken from the flange at the manufacturer's discretion.

Provided the results of both further tests comply with clause **21** all the material represented shall be deemed to comply with this British Standard.

If the results of either of these additional tests do not comply with clause **21**, the product from which the samples were cut shall be deemed not to comply with this British Standard. However, test pieces from two of the remaining products may be selected and prepared in accordance with clauses **18**, **19** and **20**, and, provided that they are tested in accordance with and comply with clause **21**, the remaining material represented shall be deemed to comply with this British Standard.

27.2 Impact tests

27.2.1 *General.* If the average value of the three impact tests is less than the minimum average specified in clause **25** or if one individual value is less than 70 % of the minimum average specified in clause **25**, three additional test pieces from the same samples shall be tested and the results added to those previously obtained and a new average calculated.

The new average value shall be not less than the specified minimum average in clause **25.** Not more than two of the individual values shall be less than the specified minimum average in clause **25.** Not more than one individual value shall be less than 70 % of the specified minimum average in clause **25.**

27.2.2 *Products tested on a thickness range basis* (see **22.1.1** and **22.2.1**). For products tested on a thickness range basis if the average impact test value of the selected test from the thickest product fails to comply with **27.2.1**, the product from which the samples were cut shall be deemed not to comply with this British Standard. However, the remaining material represented shall be deemed to comply with this British Standard provided test pieces from two of the remaining products selected and prepared in accordance with clauses **22**, **23** and **24** are tested and comply with clause **25** and, where applicable, **27.2.1**.

27.3 Re-heat treatment

Notwithstanding the requirements of **27.1** and **27.2**, the manufacturer shall have the right to heat treat or re-heat treat any material including material already found not to comply with clauses **21** and **25** and re-submit it for testing. Such re-heat treatment shall be limited to one repeat of the final heat-treatment cycle.

27.4 Through-thickness tests

No retesting shall be allowed without approval of the purchaser.

See also option **B.24**.

28 Wide plate and crack opening displacement (COD) data for modified grade parent plate

For wide plate and COD, data for modified parent plate shall not be supplied.

See also option **B.25.**

Section four. Specific requirements for the chemical composition and mechanical properties of weldable structural steel plates

29 General

The chemical composition and mechanical properties of weldable structural steel plates shall be as given in table 8 and 9.

Table 8. Chemical composition for plates[1]
(Figures in parentheses refer to the notes following this table.)

Grade	Chemical composition																
	C max.	Si	Mn	S max.	P max.	Cr max.	Mo max.	Nb	V	Ti max.	Ni max.	Cu max.	Al (Total) max.	N max.	Cr+Mo+Ni+Cu max.	Nb+V max.	Nb+V+Ti max.	Normal[2] supply condition
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
275D[3]	0.16	0.50 max.	1.50 max.	0.040	0.040	–	–	0.003/0.10	0.003/0.10	–	–	–	–	–	–	0.10	–	Normalized
275E	0.16	0.10/0.50	1.50 max.	0.030	0.040	–	–	–	–	–	–	–	–	–	–	–	–	Normalized
275EZ	0.16	0.10/0.50	1.50 max.	0.008	0.025	–	–	–	–	–	–	–	–	–	–	–	–	Normalized
355D[3][5]	0.18[4]	0.10/0.50	1.50 max.[5]	0.040	0.040	–	–	0.003/0.10	0.003/0.10	–	–	–	–	–	–	0.10	–	Normalized
355E[3][5]	0.18[4]	0.10/0.50	1.50 max.[5]	0.030	0.040	–	–	0.003/0.10	0.003/0.10	–	–	–	–	–	–	0.15	–	Normalized
355EM[6]	0.15	0.25/0.55	1.00/1.65	0.015	0.025	0.25	0.08	0.040 max.	0.015 max.	0.02	0.45	0.30	0.055[7]	0.010[7]	0.80		–	Normalized
355EMZ[6]	0.15	0.25/0.55	1.00/1.65	0.008	0.025	0.25	0.08	0.040 max.	0.015 max.	0.02	0.45	0.30	0.055[7]	0.010[7]	0.80		–	Normalized
450EM[6]	0.16	0.25/0.60	1.00/1.65	0.015	0.025	0.30	0.25	0.03 max.	0.08 max.	0.02	0.65	0.30	0.055[7]	0.010[7]	0.80	0.10	0.12	Quenched and tempered
450EMZ[6]	0.16	0.25/0.60	1.00/1.65	0.008	0.025	0.30	0.25	0.03 max.	0.08 max.	0.02	0.65	0.30	0.055[7]	0.010[7]	0.80	0.10	0.12	Quenched and tempered

(1) The chemical compositions apply to the following:
(a) ladle only in the case of grades 275D, 275E, 275EZ, 355D and 355E; and
(b) ladle and product in the case of grades 355EM, 355EMZ, 450EM and 450EMZ.

(2) For alternative supply conditions see clause 6.

(3) Steels may be supplied with no niobium or vanadium. If grain refining elements other than aluminium, niobium or vanadium are used, the manufacturer shall inform the purchaser at the time of the enquiry and order.

(4) For grades 355D and 355E over 16 mm thick, a maximum carbon content of 0.20 % for ladle is permitted.

(5) The carbon and manganese contents may be varied (ladle analysis) for grades 355D and 355E on the basis of an increase of 0.06 % manganese content for each decrease of 0.01 % carbon or vice versa up to a maximum manganese content of 1.60 % and a maximum carbon content of 0.20 %.

(6) The levels of the residual elements arsenic, antimony, tin, lead, bismuth and calcium shall not exceed 0.005 % for Ca, 0.010 % for Sb, Bi and Pb, 0.015 % for Sn and 0.02 % for As. Boron (B) shall not exceed 0.0005 %. These elements shall be reported as a ladle analysis only and shall be checked once every 5000 t at each manufacturing location.

(7) The soluble aluminium to nitrogen ratio shall be a minimum of 2:1. Soluble aluminium content is defined as 0.005 % less than the total aluminium content.

Table 9. Mechanical properties for plates

(Figures in parentheses refer to the notes following this table.)

Tensile strength, R_m (1)	Minimum yield strength, R_e, for thickness (in mm)							Minimum elongation, A, on a gauge length of (1)			Minimum average Charpy V-notch impact test value (2)			Grade
	Up to and including 16	Over 16 up to and including 20	Over 20 up to and including 40	Over 40 up to and including 63	Over 63 up to and including 100	Over 100 up to and including 120	Over 120 up to and including 150	80 mm (3)	200 mm (4)	5.65 $\sqrt{S_o}$	Temp.	Energy min. value	Thickness	
	N/mm² (5)	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	%	%	%	°C	J	mm	
430/580	275	265	–	–	–	–	–	23	20	22	-20	40	20	275D
430/580	275	265	265	–	–	–	–	23	20	22	-40	40	40	275E
430/580	275	265	265	–	–	–	–	23	20	22	-40	40	40	275EZ
490/640	355	345	–	–	–	–	–	20	18	20	-20	50	20	355D
490/640	355	345	345	–	–	–	–	20	18	20	-40	50	40	355E
460/620	355	345	345	340	325	315	305	20	18	20	-40	50	150	355EM
460/620	355	345	345	340	325	315	305	20	18	20	-40	50	150	355EMZ
	Up to and including 16	Over 16 up to and including 25	Over 25 up to and including 75											
550/700	450	430	415	–	–	–	–	19	17	19	-40	60	75	450EM
550/700	450	430	415	–	–	–	–	19	17	19	-40	60	75	450EMZ

(1) The tensile strength and elongation values apply up to the maximum thickness for which minimum yield strength values are specified.

(2) For the Charpy V-notch test, mid-thickness tests are also required when thickness is over 40 mm. In the case of piling material, the mid-thickness impacts shall be carried out at -30 °C instead of -40 °C.

(3) Up to and including 9 mm thick: 17 % for grades 275D, 275E and 275EZ and 16 % for grades 355D, 355E, 355EM, 355EMZ, 450EM and 450EMZ.

(4) Up to and including 9 mm thick: 16 % for grades 275D, 275E and 275EZ and 15 % for grades 355D, 355E, 355EM, 355EMZ, 450EM and 450EMZ.

(5) 1 N/mm² = 1 MPa.

Section five. Specific requirements for the chemical composition and mechanical properties of weldable structural steel sections

30 General

The requirements for the chemical composition and mechanical properties of weldable structural steel sections shall be as given in tables 10 and 11.

Table 10. Chemical composition for sections(1)
(Figures in parentheses refer to the notes following this table.)

Grade	Chemical composition																Normal(2) supply condition
	C max.	Si	Mn	S max.	P max.	Cr max.	Mo max.	Nb	V	Ti max.	Ni max.	Cu max.	Al (Total) max.	N max.	Cr+Mo+Ni+Cu max.	Nb+V max.	Nb+V+Ti max.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
275D	0.18	0.50 max.	1.50	0.050	0.050	–	–	–	–	–	–	–	–	–	–	–	–	As rolled
275E	0.16	0.10/0.50	1.50	0.040	0.040	–	–	–	–	–	–	–	–	–	–	–	–	As rolled or normalized
275EZ	0.16	0.10/0.50	1.50	0.008	0.025	–	–	–	–	–	–	–	–	–	–	–	–	As rolled or normalized
355D(3)	0.18(4)(5)	0.10/0.50	1.50(5)	0.040	0.040	–	–	0.003/0.10	0.003/0.10	–	–	–	–	–	–	0.10	–	As rolled
355EM(6)	0.18	0.25/0.55	1.60	0.015	0.025	0.25	0.08	0.04 max.	0.08 max.	0.02	0.30	0.35	0.06(7)	0.014(7)	0.80	0.10	0.12	As rolled or normalized
355EMZ(6)	0.18	0.25/0.55	1.60	0.008	0.025	0.25	0.08	0.04 max.	0.08 max.	0.02	0.30	0.35	0.06(7)	0.014(7)	0.80	0.10	0.12	As rolled or normalized

(1) The chemical compositions apply to the following:

(a) ladle analysis only in the case of grades 275D, 275E, 275EZ and 355D; and

(b) ladle and product in the case of grades 355EM and 355EMZ.

(2) For alternative supply conditions see clause 6.

(3) The steels may be supplied with no niobium or vanadium. If grain refining elements other than aluminium, niobium or vanadium are used, the manufacturer shall inform the purchaser at the time of enquiry and order.

(4) For grades 355D and over 16 mm thick, a maximum carbon content of 0.20 % for ladle is permitted.

(5) The carbon and manganese contents may be varied (ladle analysis) for grades 355D on the basis of an increase of 0.06 % manganese for each decrease of 0.01 % carbon or vice versa up to a maximum manganese content of 1.60 % and a maximum carbon content of 0.20 %.

(6) The levels of the residual elements arsenic, antimony, boron, tin, lead, bismuth and calcium shall not exceed 0.005 % Ca, 0.010 % for Sb, Bi, Pb, 0.015 % for Sn, and 0.02 for As. Boron (B) shall not exceed 0.0005 %. These elements shall be reported as a ladle analysis only and shall be checked once every 5000 t at each manufacturing location.

(7) The soluble aluminium to nitrogen ratio shall be a maximum of 2:1. Soluble aluminium content is defined as 0.005 % less than the total aluminium content.

Table 11. Mechanical properties for sections
(Figures in parentheses refer to the notes following this table.)

Tensile strength, R_m	Minimum yield strength, R_e, for thickness (in mm)			Minimum elongation, A, on gauge length of		Minimum average Charpy V-notch impact test value		Grade
	Up to and including 16	Over 16 up to and including 20	Over 20 up to and including 40	200 mm(1)	$5.65\sqrt{S_o}$	Temp.	Energy min. value	
N/mm²(2)	N/mm²	N/mm²	N/mm²	%	%	°C	J	
430/580	275	265	–	20	22	–20	40	275D
430/580	275	265	265	20	22	–40	40	275E
430/580	275	265	265	20	22	–40	40	275EZ
490/640	355	345	–	18	20	–20	50	355D
460/620	355	345	345	18	20	–40	50	355EM
460/620	355	345	345	18	20	–40	50	355EMZ

(1) Up to and including 9 mm thick: 16 % for grades 275E, 275E and 275EZ and 15 % for grades 355D, 355EM and 355EMZ.

(2) 1 N/mm² = 1 MPa.

Section six. Specific requirements for the chemical composition and mechanical properties of weldable structural steel seamless tubulars

31 General

The requirements for the chemical composition and mechanical properties of weldable structural steel tubulars shall be as given in table 12 and table 13.

Table 12. Chemical composition for seamless tubulars (1)

(Figures in parentheses refer to the notes following this table.)

Grade	Chemical composition																
	C max.	Si	Mn	S max.	P max.	Cr max.	Mo max.	Nb	V	Ti max.	Ni max.	Cu max.	Al (Total) max.	N max.	Cr+Mo+Ni+Cu max.	Nb+V max.	Nb+V+Ti max.	Normal (2) supply condition
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
275D	0.16	0.10/0.50	1.50 max.	0.040	0.040	–	–	–	–	–	–	–	–	–	–	–	–	As rolled or normalized
275E	0.16	0.10/0.50	1.50 max.	0.040	0.040	–	–	–	–	–	–	–	–	–	–	–	–	Normalized
355D (3)	0.18 (4)	0.10/0.50	1.50 max. (4)	0.040	0.040	–	–	0.003/0.10	0.003/0.10	–	–	–	–	–	–	0.10	–	As rolled or normalized
355EM (5)	0.18	0.25/0.55	1.60 max.	0.015	0.025	0.25	0.08	0.04 max.	0.08 max.	0.02	0.30	0.35	0.06 (6)	0.014 (6)	0.80	0.10	0.12	Normalized
450EM (5)	0.18	0.25/0.55	1.00/1.65	0.015	0.025	0.30	0.25	0.03 max.	0.08 max.	0.04	0.65	0.30	0.06 (6)	0.014 (6)	0.80	0.10	0.12	Quenched and tempered

(1) The specified chemical compositions apply to the following:

(a) ladle only in the case of grades 275D, 275E and 355D; and

(b) ladle and product in the case of grades 355EM and 450EM.

(2) For alternative supply conditions see clause 6.

(3) Steels may be supplied with no niobium or vanadium. If grain refining elements other than aluminium, niobium or vanadium are used, the manufacturer shall inform the purchaser at the time of enquiry and order.

(4) For each reduction of 0.01 % of carbon below the specified value an increase of 0.06 % manganese above the specified value is permitted.

(5) The levels of the residual elements arsenic, antimony, boron, tin, lead, bismuth and calcium shall not exceed 0.005 % Ca, 0.010 % for Sb, Bi, Pb, 0.015 % for Sn, and 0.02 % for As. Boron (B) shall not exceed 0.0005 %. These elements shall be reported as a ladle analysis only and shall be checked once every 5000 t at each manufacturing location.

(6) The soluble aluminium to nitorgen ratio shall be a minimum of 2:1. Soluble aluminium content is defined as 0.005 % less than the total aluminium content.

Table 13. Mechanical properties for seamless tubulars

(Figures in parentheses refer to the notes following this table.)

Tensile strength, R_m	Minimum yield strength, R_e, for thickness (in mm)							Grade
	Up to and including 16	Over 16 up to and including 20	Over 20 up to and including 40	200 mm (1)	$5.65\sqrt{S_o}$	Temp.	Energy min. value	
N/mm² (2)	N/mm²	N/mm²	N/mm²	%	%	°C	J	
430/580	275	265	–	20	22	-20	40	275D
430/580	275	265	265	20	22	-40	40	275E
490/640	355	345	–	18	20	-20	50	355D
460/620	355	345	345	18	20	-40	50	355EM
550/700	450	430	415	17	19	-40	60	450EM

(1) Up to and including 9 mm thick: 16 % for grades 275D and E and 15 % for grades 355D, 355EM and 450EM.

(2) 1 N/mm² = 1 MPa.

Appendices

Appendix A. Comparison between grades in this standard and BS 4360

Tables 14 to 16 give comparisons between the grades used in this standard for plates, sections and seamless tubulars respectively and those in appendix H of BS 4360 : 1986.

Table 14. Plates: comparison between grades in this standard and BS 4360

This standard				BS 4360			
Grade	Tensile strength	Minimum yield strength at 16 mm	Charpy V-notch impact	Grade	Tensile strength	Minimum yield strength at 16 mm	Charpy V-notch impact 27 J at *
	N/mm^2	N/mm^2	40 J at °C		N/mm^2	N/mm^2	°C
275D	430/580	275	−20*	43D	430/580	275	−20
275E	430/580	275	−40*	43EE	430/580	275	−50
275EZ	430/580	275	−40*	—	—	—	—
			50 J at °C				
355D	490/640	355	−20*	50DD	490/640	355	−30
355E	490/640	355	−40*	50EE	490/640	355	−50
355EM	460/620	355	−40†	—	—	—	—
355EMZ	460/620	355	−40†	—	—	—	—
			60 J at °C				
450EM	550-700	450	−40†	55 F	550/700	450	−60
450EMZ	550-700	450	−40†	—	—	—	—

*Charpy specimens orientated parallel to principal rolling direction.

†Charpy specimens orientated transverse to principal rolling direction.

Table 15. Sections: comparison between grades in this standard and BS 4360

This standard				BS 4360			
Grade	Tensile strength	Minimum yield strength at 16 mm	Charpy V-notch impact*	Grade	Tensile strength	Minimum yield strength at 16 mm	Charpy V-notch impact 27 J at*
	N/mm^2	N/mm^2	40 J at °C		N/mm^2	N/mm^2	°C
275D	430/580	275	−20	43D	430/580	275	−20
275E	430/580	275	−40	43DD	430/580	275	−30
275EZ	430/580	275	−40	—	—	—	—
			50 J at °C				
355D	490/640	355	−20	50E	490/640	355	−40
355EM	460/620	355	−40	—	—	—	—
355EMZ	460/620	355	−40	—	—	—	—

*Charpy specimens orientated parallel to principal rolling direction.

Table 16. Seamless tubulars: comparison between grades in this standard and BS 4360

This standard				BS 4360			
Grade	**Tensile strength**	**Minimum yield strength at 16 mm**	**Charpy V-notch impact***	**Grade**	**Tensile strength**	**Minimum yield strength at 16 mm**	**Charpy V-notch impact* 27 J at**
	N/mm^2	N/mm^2	**40 J at** °C		N/mm^2	N/mm^2	°C
275D	430/580	275	−20	43D	430/580 (min)	275	−20
275E	430/580	275	−40	43EE	430/580	275	−50
			50 J at °C				
355D	490/640	355	−20	50D	490/640	355	−20
355EM	460/620	355	−40	50EE	490/640	355	−50
			60 J at °C				
450EM	550/700	450	−40	55EE	550/700	450	−50

*Charpy specimens orientated parallel to the seamless tubular axis.

Appendix B. Options (see 4.2)

B.1 Details of manufacturing procedures to be supplied by the manufacturer for all modified grades

The following information shall be supplied by the manufacturer to the purchaser at the time of the enquiry and order.

(a) Location and name of steel mill(s).

(b) Recent production data to demonstrate that the values proposed for ladle and product analysis are achievable.

(c) Steel manufacturing procedures as follows:

(1) steelmaking process;

(2) proportions of scrap and hot metal charge;

(3) nominal mass of heat;

(4) any hot-metal treatment, e.g. degassing, desulphurization or sulphide treatment technique;

(5) ingot or continuous cast (concast).

(d) Segregation control procedures (including electro-magnetic stirring, etc.) for continuous cast steel.

(e) Control of sequential casting (for continuous casting).

(f) Ingot or slab size including plate thickness ranges on each size.

(g) Details of sulphur printing or alternative method of quality grading and frequency of checks (for continuous casting).

(h) Rolling procedures.

(i) Dehydrogenation procedures.

(j) Normalizing procedures or alternative procedures, e.g. quenching, Q, and tempering, T ($Q + T$).

(k) Recent production data to demonstrate that the Charpy V-notch impact values specified in this standard are achievable.

(l) Information on the effect of extended times at stress relieving temperatures on tensile and Charpy V-notch impact properties to cover the effects of a second stress relief in case of repair.

(m) Details of the quality control procedures to be implemented by the manufacturer during production which should clearly identify all inspection points.

The manufacturer shall not change any of the above items without the approval of the purchaser.

B.2 Limits for concast modified grades

The continuous casting process shall be limited to the production of material up to and including 50 mm except in the case of piling, where the use of concast material up to and including 65 mm in thickness is permitted (see **5.3**).

B.3 Reduction ratios

In consultation between the manufacturer and the purchaser, different reduction ratios shall be specified (see **5.3.2**).

B.4 Cold-forming procedures for plate of modified grades (see 5.4)

The manufacturer shall provide the following data on the effect of cold-forming plates at outside diameter to thickness ratios of 10:1, 15:1 and 20:1. This shall be provided from actual rolling trials or on simulated tensile tests at 5 %, 7.5 % and 10 % strain.

All specimens shall be extracted from the outer subsurface position of the strained segment and parallel to the circumference.

The test frequency shall be one set of the following tests per mill source per manufacturing route.

(a) *Trial material:* ingot 80 mm max., concast 50 mm max.

(b) *Condition:* as follows:

(1) as rolled and aged 1 h at 150 °C;

(2) as rolled and aged 1 h at 150 °C plus stress relief for 4 h at 600 ± 20 °C;

(3) as rolled and aged 1 h at 250 °C;

(4) as rolled and aged 1 h at 250 °C plus stress relief for 4 h at 600 ± 20 °C.

(c) *Ageing.* The following tests shall be carried out for each ageing condition.

(1) *Tensile:* One test at ambient temperature shall be carried out and shall comply with the values given in table 9 for the appropriate grade.

(2) *Charpy V-notch impact:* Transition curves shall be derived from unstrained, strained and strain-aged material. Tests shall be performed from +20 ° C down to −80 °C at 20 °C intervals; three specimen shall be tested at each temperature, and shall have the following minimum values at −40 °C.

(i) For grade 355EM and 355EMZ, an average value of 36 J and an individual value of 26 J.

(ii) For grades 450EM and 450EMZ, an average value of 45J and an individual value of 32 J.

B.5 Hot-forming procedures for plate of modified grades

At the time of the enquiry and order the manufacturer shall provide general information on the method and effect of hot-forming on material properties.

B.6 Alternative supply condition

The purchaser shall approve an alternative supply condition proposed by the manufacturer/supplier, e.g. as rolled or TMCR steel for plate and sections (see clause **6**).

NOTE. TMCR material is unsuitable for subsequent normalizing or hot forming in the normalizing temperature range or at lower temperatures as a significant deterioration in mechanical properties will occur.

B.7 Details of heat treatment procedures for plate grade 450

The manufacturer shall provide details of austenitizing and tempering temperatures, soaking times and methods of control (see **6.2**).

B.8 Manufacturer's proposed analysis for modified grades

At the time of the enquiry and order, the manufacturer shall advise the purchaser of the ladle and product analysis ranges, within the specified ranges in tables 8, 10 and 12, to which he proposes to work. This shall cover all elements listed in tables 8, 10 and 12 and also include residual elements required to be reported for each material type and manufacturing route (see clause **7** and tables 8, 10 and 12).

B.9 Weldability tests (see clause 8)

B.9.1 Selection of weldability tests (modified steels only)

Weldability tests shall be performed by means of either or both of the series of tests described in appendices F and G. The purchaser shall specify which of the tests in appendices F and/or G are to be carried out.

NOTE. Weldability tests are only required for plates exceeding 40 mm in thickness and for rolled seamless tubulars and sections over 25 mm in thickness.

B.9.2 Materials sampling

Plates shall be selected whose mechanical/chemical properties and manufacturing routes are typical for the grade(s) of material the manufacturer intends to supply in production.

The materials for the weldability evaluation shall be selected from the top end of the planned production range of carbon equivalent values and shall be approved by the purchaser.

B.9.3 Retention of test samples

Representative test samples and significant sized pieces of untested material shall be uniquely identified and stored for a period of 1 year during which time they shall be made available for additional testing/inspection if so required by the purchaser.

B.9.4 Data reporting

On completion of each weld testing programme and verification of all test results the steel manufacturer shall submit a report to the purchaser.

B.10 Ultrasonic testing for internal soundness

Grades other than modified grades shall be ultrasonically tested to verify that the plates comply with the internal soundness of grade LC1 of BS 5996 (see **9.1.2**).

B.11 Ultrasonic, magnetic particle and dye penetrant procedures

Written ultrasonic, magnetic particle inspection (MPI) and dye penetrant procedures shall not be submitted by the manufacturer (see **9.4**).

B.12 Colour coding

Widths of painted bands shall be less than 50 mm (see **11.2**).

B.13 Test certificates for ex-mill supply

An additional number of copies, as defined by the purchaser, of all relevant test certificates and reports shall be sent to a nominated address (see **12.1**).

B.14 Length and width tolerances for plates

Plates shall be supplied machine gas cut or re-sheared to the restricted length and width tolerances given in table 17 (see clause **15.2** and **15.3**).

Table 17. Restricted length and width tolerances for plates

Ordered thickness	Tolerances
mm	mm
Up to and including 40	−0 +6
Over 40 up to and including 100	−0 +10
Over 100 up to and including 150	−0 +13

B.15 Thickness tolerances for plates: all over ordered thickness

Plates shall be supplied to the thickness tolerances given in table 18 (see **15.4**).

Table 18. Thickness tolerances for plates: all over ordered thickness

Ordered thickness	Width of plate (mm)				
	Up to and including 2 000	Over 2 000 up to and including 2 500	Over 2 500 up to and including 3 000	Over 3 000 up to and including 3 500	Over 3 500 up to and including 4 000
mm	mm	mm	mm	mm	mm
Less than 5	−0 +0.80	−0 +1.00	−0 +1.00	—	—
5 to less than 8	−0 +0.90	−0 +1.20	−0 +1.60	−0 +1.60	—
8 to less than 25	−0 +1.10	−0 +1.30	−0 +1.60	−0 +1.60	−0 +1.90
25 to less than 40	−0 +1.10	−0 +1.40	−0 +1.60	−0 +1.70	−0 +1.90
40 to less than 80	−0 +1.20	−0 +1.60	−0 +1.70	−0 +1.90	−0 +2.10
80 up to and including 150	−0 +2.20	−0 +2.30	−0 +2.40	−0 +2.50	−0 +2.50

B.16 Thickness tolerances for plates: all under ordered thickness

Plates shall be supplied to the thickness tolerances given in table 19 (see **15.4**).

B.17 Special flatness tolerances for plates

Plates shall be supplied to the tolerances given in table 20 (see **15.6**).

For steel grades with a specified minimum yield strength exceeding 360 N/mm^2 the flatness tolerances given in table 20 shall be increased by 50 %.

Deviations shall be measured at a point a minimum of 20 mm from the longitudinal edges and a minimum of 50 mm from the transverse edge.

When distances between points of contact are between 500 mm and 1000 mm the deviation shall be obtained by taking the distance between points of contact and calculating proportionally from the deviation given for a 1000 mm straightedge in table 20.

Table 19. Thickness tolerances for plates: all under ordered thickness

Ordered thickness	Width of plate (mm)				
	Up to and including 2 000	Over 2 000 up to and including 2 500	Over 2 500 up to and including 3 000	Over 3 000 up to and including 3 500	Over 3 500 up to and including 4 000
mm	mm	mm	mm	mm	mm
Less than 5	−0.80 +0	−1.00 +0	−1.00 +0	—	—
5 to less than 8	−0.90 +0	−1.20 +0	−1.60 +0	−1.60 +0	—
8 to less than 25	−1.10 +0	−1.30 +0	−1.60 +0	−1.70 +0	−1.90 +0
25 to less than 40	−1.10 +0	−1.40 +0	−1.60 +0	−1.70 +0	−1.90 +0
40 to less than 80	−1.20 +0	−1.60 +0	−1.70 +0	−1.90 +0	−2.10 +0
80 up to and including 150	−2.20 +0	−2.30 +0	−2.40 +0	−2.50 +0	−2.50 +0

Table 20. Special flatness tolerances for plates

Ordered thickness	Straight-edge length selected	Permissible deviations for ordered widths (mm)							
		Less than 1 500	1 500 to less than 2 000	2 000 to less than 2 500	2 500 to less than 2 750	2 750 to less than 3 000	3 000 to less than 3 250	3 250 to less than 3 500	3 500 to less than 4 000
mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
3 to less than 4	1000	3	4	5	—	—	—	—	—
	2000	8	11	15	—	—	—	—	—
4 to less than 6	1000	3	4	4	5	—	—	—	—
	2000	7	11	15	18	—	—	—	—
6 to less than 8	1000	3	4	4	4	5	—	—	—
	2000	7	9	11	12	14	—	—	—
8 to less than 10	1000	3	3	3	3	4	4	4	—
	2000	6	7	8	9	10	12	16	—
10 to less than 20	1000	3	3	3	3	3	4	4	4
	2000	6	6	7	9	9	10	10	12
20 up to and	1000	3	3	3	3	3	3	3	4

B.18 Purchaser's selection and identification of test samples prior to products being cut to ordered size

The purchaser shall randomly select and identify test samples in accordance with clauses **18**, **19**, **22** and **23** prior to the products being cut to ordered size (see clause **17**).

B.19 Purchaser's selection and identification of test samples after products have been cut to ordered size

The purchaser shall randomly select and identify test samples in accordance with clauses **18**, **19**, **22** and **23** after the products have been cut to ordered size (see clause **17**). In this case the purchaser shall accept the material from which the test samples have been cut provided that the test results comply with this British Standard.

B.20 Purchaser's witnessing of mechanical tests

The mechanical tests applicable to the purchaser's order shall be carried out in the purchaser's presence (see clause **17**).

B.21 Purchaser's visual inspection

With respect to surface condition (see **9.1.1**, **9.2.1** and **9.3.1**) and/or product marking (see clause **11**) and/or relevant dimensional and shape tolerances (see section two), the manufacturer shall make available for the purchaser's visual inspection all or a random selection of the items produced for his order.

B.22 Simulated post-weld heat treatment

The purchaser shall specify a post-weld heat treatment temperature other than 600 ± 20 °C (see **17.2.2**).

NOTE. In this case the properties to be obtained should be agreed.

B.23 Strain-age tests for modified grades

(see **25.4**)

Strain-age testing shall be carried out for plate over 12.5 mm thickness in grades 355EM, 355EMZ, 450EM and 450EMZ.

One plate thickness from each of three casts per process route and per manufacturing location shall be tested using Charpy V-notch impacts from the subsurface position (2 mm) cut transverse to the direction of rolling.

Two samples of material shall be plastically strained 5 % and then one aged for 1 h at 250 °C and the other for 1 h at 150 °C.

Charpy V-notch impact tests shall be performed on unstrained, strained and strain-aged samples at −40 °C and shall achieve the following minimum values.

(a) For grades 355EM and 355EMZ, an average value of 36 J and an individual value of 26 J.

(b) For grades 450EM and 450EMZ, an average value of 45 J and an individual value of 32 J.

B.24 Through-thickness testing for Z grades (see clause **26**)

B.24.1 General

Through-thickness testing shall be carried out in the final heat-treatment condition. Testing is not required for thicknesses below 25 mm.

The frequency of testing shall be:

(a) each parent product when S is > 0.005 % $\leqslant 0.008$ % S (ladle);

(b) one plate from each cast when S is $\leqslant 0.005$ % S (ladle).

B.24.2 Test pieces

Six test pieces shall be taken at the locations detailed in figure 6. Test pieces shall have a diameter of 10 mm.

For plate thicknesses less than or equal to 40 mm the full plate thickness shall be tested by attaching extension pieces on either side.

For plate thicknesses greater than 40 mm test pieces 'A' shall be taken from one surface of the plate and test pieces 'B' shall be taken from the opposite surface of the plate (see figure 6).

Extension pieces shall be friction welded to the test samples (see figure 7).

B.24.3 Test results

When the six test pieces are tested in accordance with BS 6780 the test results shall be as follows:

(a) the through-thickness tensile strength shall be not less than 80 % of the minimum specified tensile strength;

(b) the short-transverse reduction in area (STRA) shall have a minimum average value of 35 % and an individual value of 25 %.

B.25 Wide plate and COD data for modified-grade parent plate (see clause 28)

For plates of thickness greater than 100 mm the steel manufacturer shall either:

(a) provide wide plate data of parent plate applicable to the type of steel to be supplied; or

(b) in the absence of relevant wide plate data, shall COD test sample plates of thicknesses up to 150 mm in accordance with BS 5762 using displacement control. The subsidiary specimen geometry is permitted. The tests shall be carried out after simulated post-weld treatment at 600 ± 20 °C. Three tests per plate thickness shall be performed at −10 °C. The COD specimens shall be taken transverse to the principal rolling direction of the plate and shall be through-thickness notched.

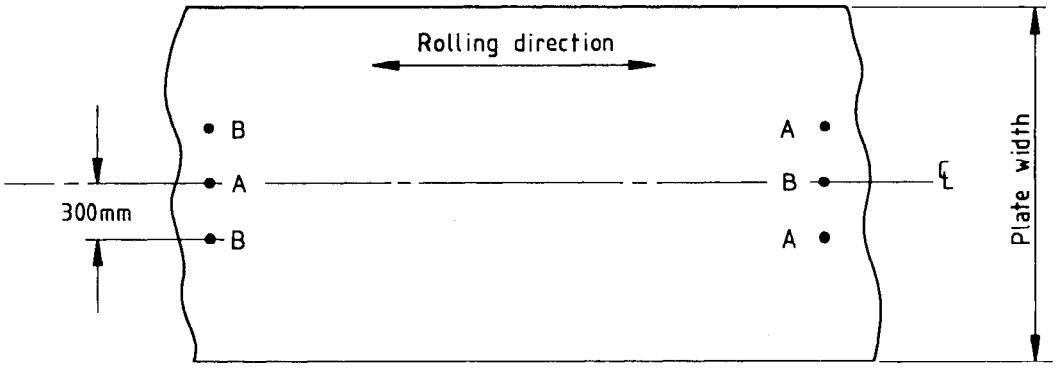


Figure 6. Through-thickness tensile test piece locations (see **B.24.2**)

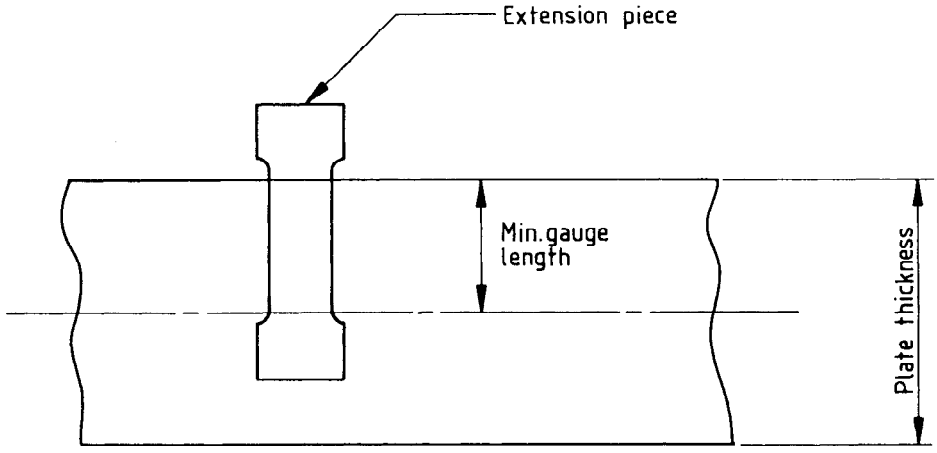
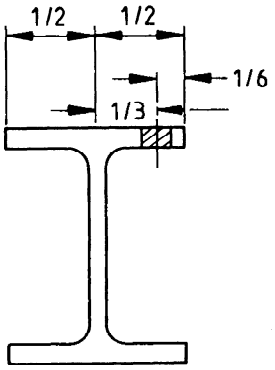


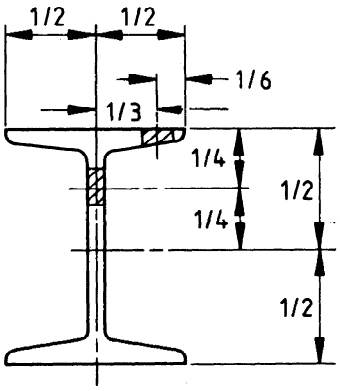
Figure 7. Through-thickness tensile test piece location within plate with thickness > 40 mm (see **B.24.2**)

Appendix C. Positions of test samples for tensile test

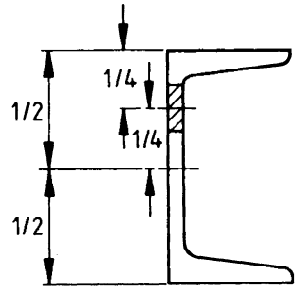
The positions of test samples for tensile testing shall be as shown in figure 8.



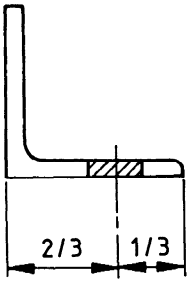
(a) Sections with parallel flanges



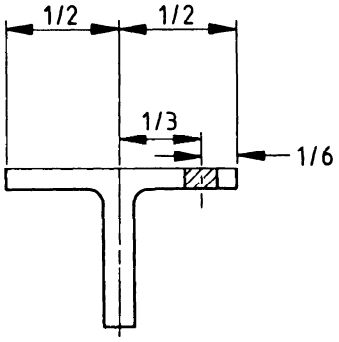
(b) Sections with tapered flanges



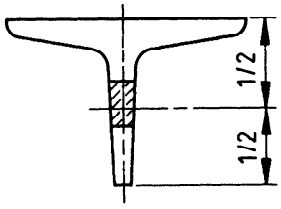
(c) Channels



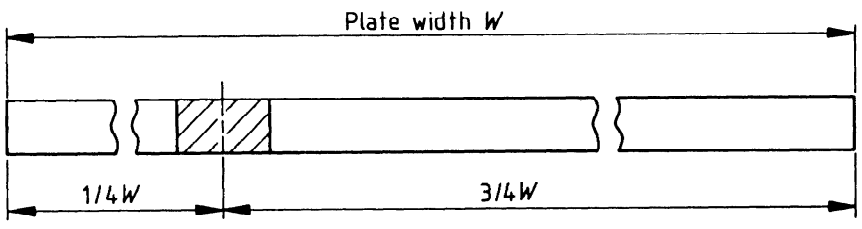
(d) Equal and unequal angles



(e) T-bars cut from sections with parallel flanges; rolled short stalk T-bars; rolled long stalk T-bars with parallel flanges



(f) T-bars cut from sections with tapered flanges; rolled long and short stalk T-bars with tapered flanges



(g) Plates

Figure 8. Positions of test samples for tensile test (see clause 19)

Appendix D. Position of test piece to be taken from tensile test sample when two rolled surfaces cannot be retained

The position of the test piece to be taken from tensile test samples when two rolled surfaces cannot be retained shall be as shown in figure 9.

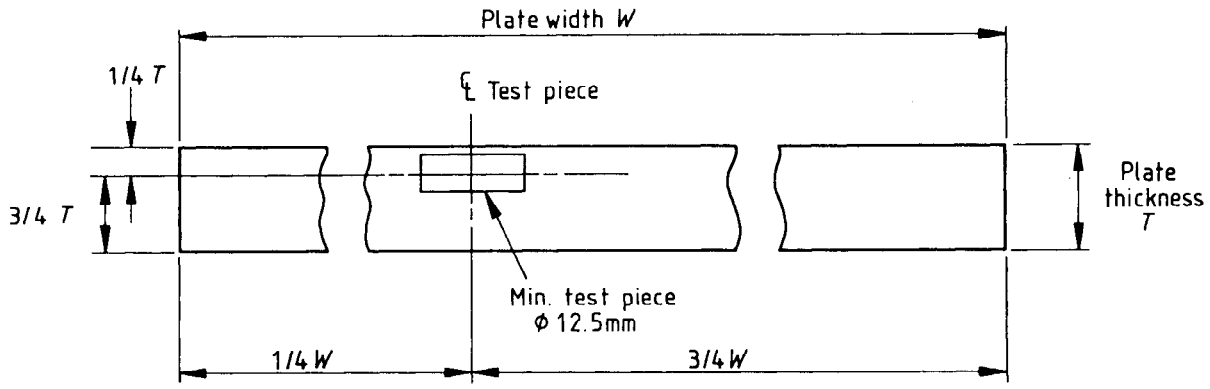
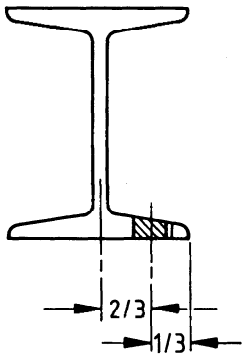


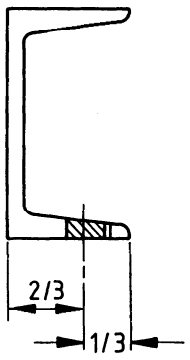
Figure 9. Position of test piece to be taken from tensile test sample when two rolled surfaces cannot be retained (see clauses **19** and **20**)

Appendix E. Positions of test samples for impact tests

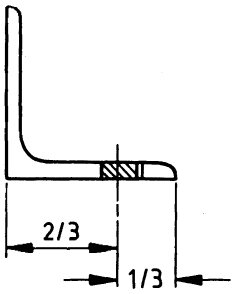
The positions of test samples for impact tests shall be as shown in figure 10.



(a) Sections

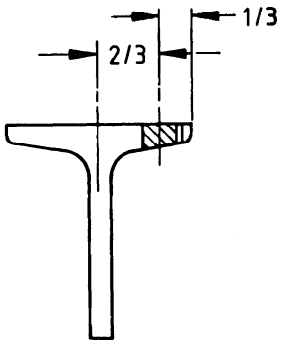


(b) Channels

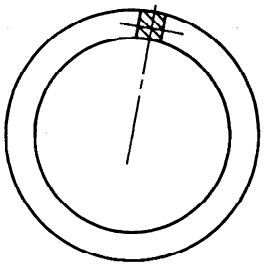


NOTE. The test piece may be taken from either leg of unequal angles.

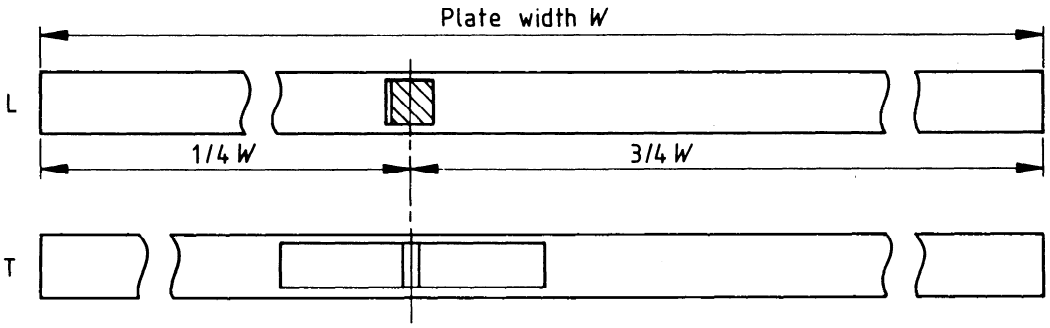
(c) Equal and unequal angles



(d) T-bars cut from universal beams; T-bars cut from universal columns; rolled short stalk T-bars; rolled long stalk T-bars



(e) Tubulars



L is the longitudinal direction (mm)
T is the traverse direction (mm) (see figure 5)

NOTE. Additional samples are taken from mid-thickness at the position shown.

(f) Plates > 40 mm thick

Figure 10. Positions of test samples for impact tests (see clauses **23** and **24**)

Appendix F. Weldability testing for modified grades and mechanical testing of butt welds

F.1 General requirements

A series of butt welds with arc energies in accordance with **F.3.4** shall be made prior to the commencement of production.

The welds shall be carried out in accordance with normal fabrication practices but square-edge weld preparation shall be used for one side of the preparation. The welds shall comply with the mechanical properties specified in **F.5.**

NOTE. Precautions should be taken to prevent the occurence of defects which could invalidate the test.

In addition, if specified at the discretion of the purchaser, further welds shall be carried out where sufficient grain coarsened heat-affected zone (HAZ) is produced so that the fatigue-crack of the COD test piece samples at least 15 % of grain-coarsened HAZ (as defined in **F.4.3.1**).

F.2 Welding procedure

The manufacturer shall submit detailed welding procedures for review and approval by the purchaser at least 3 weeks prior to commencement of welding. The procedures shall include wire or electrode size, welding parameters, welding position and other relevant parameters, e.g. number of submerged arc welding (SAW) wires, iron power additions, weld bevel angle and a typical photomicrograph of a section from the weld to show the alignment of the fusion line, together with a measurement of the percentage of grain-coarsened HAZ, according to the method given in figure 16.

Welding consumables, which have previously demonstrated consistently high, i.e. above 0.25 mm, COD values at -10 °C, shall only be used. Welding of test plates shall be carried out by qualified personnel approved by the purchaser for use on offshore structures or sub-assemblies.

F.3 Plate butt-weld requirements

F.3.1 Test plate dimensions

The test plate thicknesses shall correspond to the maximum thickness of the ranges detailed in table 21.

The length of each test plate shall be in the principal direction of rolling.

The length and width of each welded test plate shall be sufficient to accommodate the testing requirements of this appendix plus any retests. The width of the welded test piece shall not be less than 500 mm or 10 times the thickness, whichever is greater, to a maximum of 750 mm.

F.3.2 Bevel detail

For all test welds a square-edge weld preparation shall be adopted for one side of the preparation. The other side of the preparation shall consist of a single bevel (see figure 11(a)). For test welds in excess of 60 mm a J-type preparation may be used.

F.3.3 Welding processes

Tack welds and initial root pass of each test plate may be deposited by the gas metal arc or shielded metal are welding (SMAW) or flux-cored are welding (FCAW) process. Subsequent weld passes shall be deposited by FCAW or SAW, as appropriate.

F.3.4 Nominal arc energy

NOTE. The nominal arc energies for each weld pass apply unless other values consistent with proposed fabrication procedures or base material are agreed at the time of enquiry and order.

Nominal arc energies for each weld pass shall be:

FCAW	0.6 kJ/mm ± 0.1 kJ/mm;
SAW	3.0 kJ/mm ± 0.2 kJ/mm, for grade 355 only.
SAW	5.0 kJ/mm ± 0.2 kJ/mm, for grade 355 only.
SAW	3.5 kJ/mm ± 0.2 kJ/mm, for grade 450 and also for grade 355 if the 5.0 kJ/mm test produces results below the purchaser's acceptance criteria.

Arc energy, A (in kJ/mm) shall be calculated from the following equation:

$$A = \left(\frac{VI}{W}\right)10^{-3}$$

where

V is the arc voltage (in V);

I is the welding current (in A);

W is the welding speed (in mm/s).

For the purposes of this standard the arc energy for tandem arc welding shall be calculated as the sum of the individual arc energies.

F.3.5 Heat treatment

After welding, grade 355 test welds, which are to be tested in the PWHT condition, shall be post-weld heat treated at either 600 ± 20 °C or at another temperature to be specified by the purchaser. They shall be subjected to a soaking period of either not less than 1 h per 25 mm thickness of plate or 4 h, whichever is the greater. Heating and cooling rates shall be in accordance with BS 5500.

For grade 450 test welds, post-weld heat treatment shall be within the temperature range 550 °C to 620 °C, with a maximum temperature of 25 °C below the tempering range on the test certificate, for either 1 h per 25 mm thickness of plate or 4 h, whichever is the greater.

Table 21. Weldability test requirements for butt welds

Maximum thickness range, *t*	Condition	Nominal arc energies (kJ/mm)			
		FCAW* 0.6	SAW 3.0	SAW 5.0	SAW 3.5
		P = 125 °C *I* = 250 °C†‡	*P* = 125 °C *I* = 250 °C	*P* = 125 °C *I* = 250 °C	*P* = 125 °C *I* = 250 °C
mm 355EMZ 40 < *t* ⩽ 50 Concast	As welded	√	√	√	§
40 < *t* ⩽ 50 Concast	PWHT	√	√	√	§
40 < *t* ⩽ 150 Ingot	As welded	√	√	√	§
40 < *t* ⩽ 150 Ingot	PWHT	√	√	√	§
450EMZ‖ 40 < *t* ⩽ 75	As welded	–	–	¶	√
40 < *t* ⩽ 75	PWHT	–	–	¶	√
Tubulars and sections** 25 < *t* ⩽ 40	As welded	√	√	–	√

*Flux-cored arc welding.

†*P* is the minimum pre-heat temperature (in °C); *I* is the maximum interpass temperature (in °C).

‡For CEV = 0.44 use *P* = 150 °C.

§Grade 355EMZ tests may also be required at 3.5 kJ/mm if tests at 5.0 kJ/mm produce results below the purchaser's acceptance criteria.

‖Ingot or concast.

¶Grade 450EMZ not to be welded above 3.5 kJ/mm.

**See option B.9.1.

F.4 Mechanical testing

F.4.1 General

A series of mechanical tests shall be carried out in accordance with table 22. A sufficient amount of each test weld should be prepared to permit repeat testing particularly in case of invalid COD tests (see **F.4.3.2**).

F.4.2 Charpy V-notch impact tests

Charpy V-notch test specimen locations shall be in accordance with figure 11 and testing shall be carried out in accordance with BS 131 : Part 2.

Prior to notching, all samples shall be etched to allow the notch location to be marked.

Subsequent to testing, all fusion-line specimens taken from the straight edge (SE) shall be sectioned to verify a correct notch.

Table 22. Mechanical test requirements for each butt weld*

Type of test	No. of tests	Position of tests	Acceptance criteria
Macro/hardness	2	See **F.4.4** and figure 12	325 Hv10, except for 0.6 kJ/mm arc energy when acceptance value is 350 Hv10 (see **F.5.1**(c))
Charpy V-notch	One set of 3 tests per position	Position of tests as follows: (a) transverse to plate rolling direction; (b) at FL, FL+2 and FL+5 on specimens from cap, mid-thickness and root from both straight edge and bevel edges (see **F.4.2**, **F.5.1**(a) and figure 11)	Tested at −40 °C to meet the following: (a) for grade 355, a minimum average of 36 J and a minimum individual value of 26 J; (b) for grade 450, a minimum average of 45 J and a minimum individual value of 32 J (see **F.5.1**(a))
COD	3 tests per position	Position of tests as follows: (a) transverse to plate rolling direction; (b) at each of the following positions: (1) GCHAZ (2) SCHAZ/ICHAZ boundary (3) weld metal (See **F.4.3.2**)	Tested at −10 °C to meet a COD value as defined by the purchaser (see **F.5.1**(b))
Additional COD†	3 tests per position	Fatigue-crack-tip to sample at least 15 % of grain-coarsened HAZ (see **F.1** and **F.4.3.4**)	Tested at −10 °C to meet a COD value as defined by the purchaser (see **F.5.1**(b))
Cross-weld tensile	2	Cross-weld (see **F.4.5**)	As given in tables 9, 11 and 13 (see **F.5.1**(d))

*For details of butt welds see **F.3** and table 21.

†Additional COD tests to be carried out on 3.0 kJ/mm and 5.0 kJ/mm test welds only.

F.4.3 COD tests

F.4.3.1 *Classification of HAZ structures.* When a single weld bead is deposited on a plate, the following four HAZ zones shall be defined in the plate in order moving away from the weld depending on the temperature experienced:

(a) grain-coarsened HAZ (GCHAZ) : temperature $> 1110\ ^{\circ}C \leqslant 1400\ ^{\circ}C$;

(b) fine grained HAZ (FGHAZ): temperature $> Ac_3 \leqslant 1100\ ^{\circ}C$;

(c) intercritical HAZ (ICHAZ): temperature $> Ac_1 \leqslant Ac_3$;

(d) subcritical HAZ (SCHAZ): temperature $\leqslant Ac_1$.

In a multi-pass weld some regions of the HAZ of the first pass are eliminated, others are significantly altered and others remain unaltered. In a single bevel multi-pass weld the overlapping heat affected zones that penetrate the unbevelled edge appear as shown in figure 13.

NOTE. The zones of particular importance are as follows and are highlighted in figure 14.

(a) the intercritically reheated GC HAZ (ICGCHAZ);

(b) the subcritically reheated GC HAZ (SCGCHAZ);

(c) the SCHAZ/ICHAZ boundary.

F.4.3.2 *Test requirements.* Three valid COD tests shall be conducted for each of the following:

(a) grain-coarsened HAZ (GCHAZ);

(b) the subcritical HAZ (SCHAZ)/intercritical HAZ (ICHAZ) boundary;

(c) weld metal (2 mm from the fusion line).

All COD samples shall be transverse to the plate rolling direction.

Testing shall be carried out in accordance with BS 5762 using displacement control and test pieces which shall be notched in the through-thickness direction. For thickness, $t < 75$ mm a preferred geometry specimen shall be adopted and for $t \geqslant 75$ mm a subsidiary specimen geometry $a/w = 0.3$ shall be adopted, where a is the effective crack length (in mm); w is the width of test piece (in mm).

Tests shall be checked for validity (see note) and invalid specimens shall be disregarded and the test(s) repeated.

NOTE. In addition to the requirement of BS 5762, validity of test specimens should be checked according to the following criteria.

(a) *Grain-coarsened HAZ.* To be considered a valid test, the fatigue crack should be within 0.5 mm of the fusion line and should sample all the grain-coarsened HAZ present, as shown in figure 14(a). However, if fusion line irregularities prevent this, a sample including as much grain-coarsened HAZ as possible may be accepted, if approved by the purchaser.

(b) *Subcritical/intercritical HAZ boundary.* To be considered a valid test, the fatigue crack should sample the boundary between the subcritical HAZ and the intercritical HAZ, as shown in figure 14(b). However, if fusion line irregularities prevent this a sample including as much relevant microstructure as possible may be accepted if approved by the purchaser.

(c) *Weld metal.* To be considered a valid test, 100 % of the fatigue crack should sample weld metal and 80 % should be within 2 mm of the fusion line. Additional sectioning may be necessary to examine the fracture initiation point if agreed between the purchaser and supplier.

F.4.3.3 *Sectioning methods*

F.4.3.3.1 *Grain-coarsened HAZ.* Following testing, each COD specimen shall be examined as follows to confirm that the fatigue crack sampled the grain-coarsened HAZ (GCHAZ).

(a) Remove a 15 mm slice containing the fracture face from each specimen half.

(b) Section either the sample from the weld metal side or both fracture faces parallel to the root of the machined notch as shown in figure 15.

NOTE. Specimens should be sectioned to allow examination of the central $^2/_3$ of the fatigue crack. If fracture initiation falls outside the central $^2/_3$ of the specimen sectioning should include this point.

(c) Polish and etch the exposed top face of the bottom half for micro examination as shown in figure 15.

(d) Examine and take a photomicrograph at an appropriate magnification. The recorded evidence shall show the full plate thickness.

NOTE. If the distance between the polished face and the deepest point of the fatigue crack exceeds 2 mm, as a result of excessive bowing or the existence of an irregular fatigue crack profile, additional sections may be required as agreed with the purchaser.

F.4.3.3.2 *Subcritical/intercritical HAZ boundary.* For each SCHAZ COD specimen, sectioning and documentation shall be as given in **F.4.3.3.1**.

F.4.3.3.3 *Weld metal.* For each weld metal COD specimen, only one of the two specimen halves shall be sectioned. The half containing the HAZ (not the half containing the bulk of the weld metal) shall be sectioned, prepared and photographed.

F.4.3.4 *Additional COD tests.* When additional tests are specified by the purchaser, as defined in **F.1**, the percentage of grain-coarsened areas sampled by the fatigue crack shall be calculated as shown in figure 16. This percentage should include the ICGCHAZ and SCGCHAZ adjacent to the columnar weld metal.

F.4.4 Macro/hardness surveys

Macro specimens shall be prepared from each test weld and hardness surveys shall be performed on each specimen in accordance with BS 427 and figure 12 of this standard.

Starting as close to the fusion line as possible with indents 0.75 mm between centres through to base material the centre of all indents shall be as close to as possible but clear of the fusion line.

All hardness surveys shall be performed with a 10 kg load.

F.4.5 Cross-weld tensile test

If specified by the purchaser, two cross-weld tests shall be carried out.

F.5 Specific test requirements

F.5.1 Tests in the as-welded and PWHT conditions

The test welds shall be welded from the maximum thickness of plate to be produced within the following ranges at the normal arc energies detailed in table 21.

As-welded	PWHT
$40 < t \leqslant 50$ mm concast	$40 < t \leqslant 50$ mm concast
$40 < t \leqslant 150$ mm ingot	$40 < t \leqslant 150$ mm ingot

NOTE. Where t is the thickness (in mm).

The following mechanical test requirements shall be achieved for each weld.

(a) *Charpy V-notch tests.* Specimens shall be taken transverse to the plate rolling direction at the locations detailed in figure 11 and shall be tested at −40 °C to meet the following minimum values:

(1) for grade 355, an average value of 36 J and an individual value of 26 J;

(2) for grade 450, a minimum average value of 45 J and a minimum individual value of 32 J.

Retest procedures shall be in accordance with **27.2.1**.

(b) *COD.* COD values at −10 °C shall meet the purchaser's acceptance criteria.

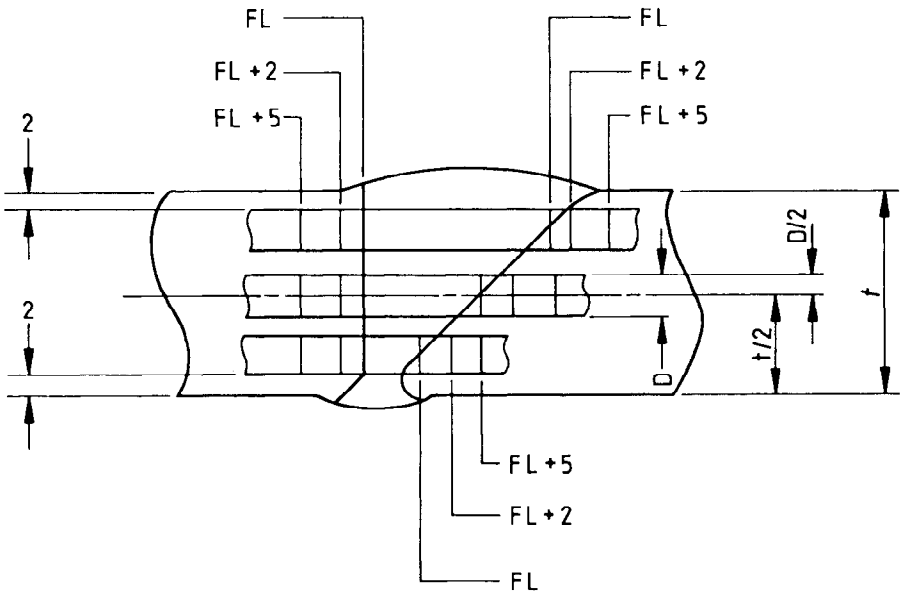
(c) *Vickers hardness.* Vickers hardness shall be 325 Hv10max., except in the case of the 0.6 kJ/mm arc energy test when the value shall be 350 Hv10max.

In the event that a retest is required, remove 2 mm to 4 mm of the surface and retest the failed area.

(d) *Cross-weld tensile tests.* The tensile strength shall not be less than the minimum specified in tables 9, 11 and 13.

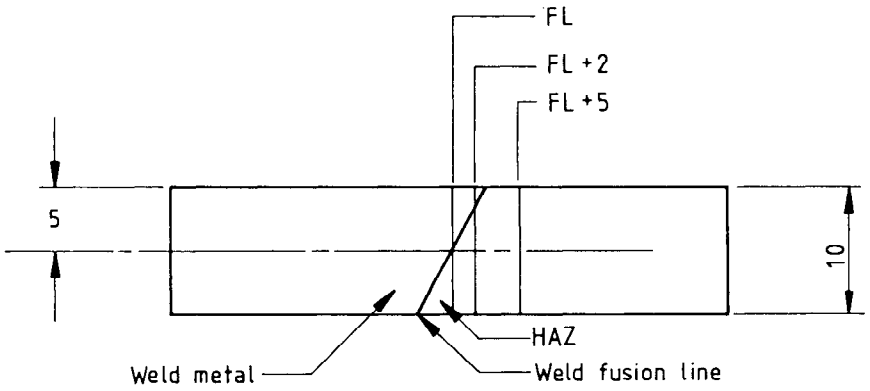
F.6 Weldability testing of seamless tubulars and sections

Where weldability testing of sections and seamless tubulars exceeding 25 mm thick is specified by the purchaser, test welds shall be prepared as given in table 21. Testing shall be confined to macro/hardness (see **F.5.1**(c)) and Charpy V-notch (see **F.5.1**(a)). COD testing (see **F.5.1**(b)) shall only be carried out at the discretion of the purchaser.



NOTE. Where t is the plate thickness (in mm); D is the specimen size (in mm).

(a) Single bevel

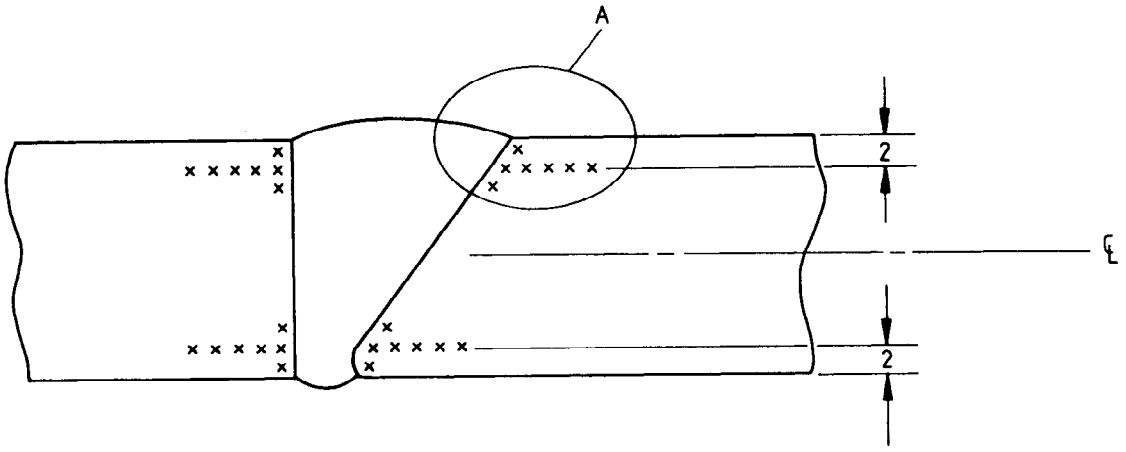


(b) Notch positions for HAZ Charpy V-notch test pieces on bevelled side of weld

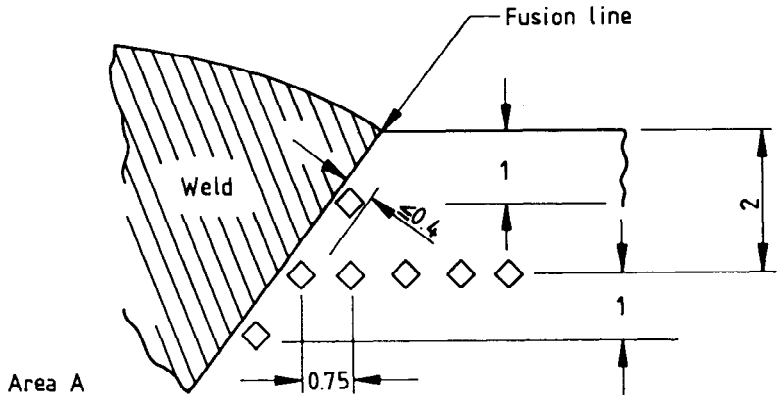
All dimensions are in millimetres.

NOTE. FL is the fusion line.

Figure 11. Location of Charpy V-notch impact test pieces for plate butt weld (see **F.3.2** and **F.4.2**)



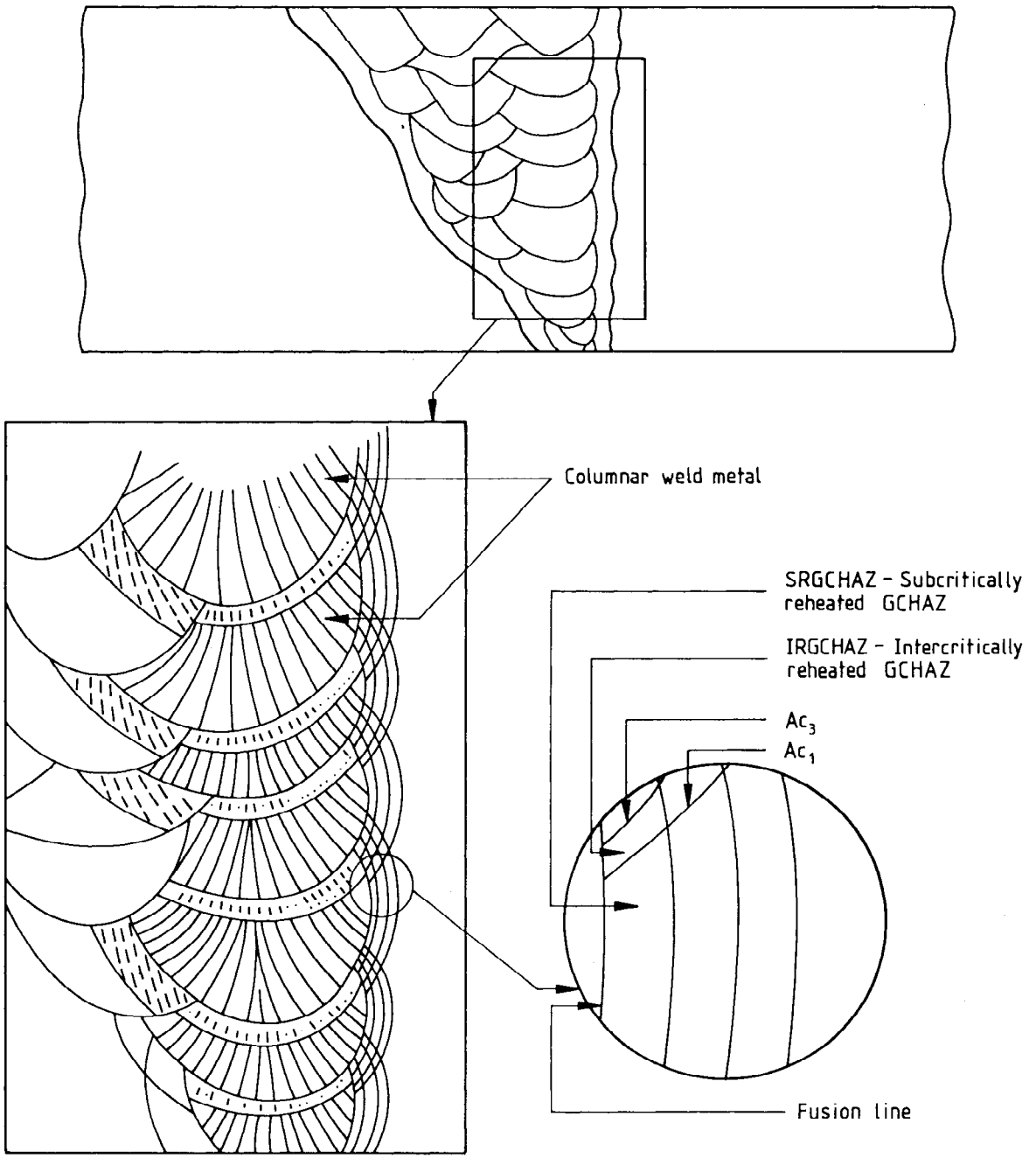
(a) General arrangement



(b) Enlargement of area A

All dimensions are in millimetres.

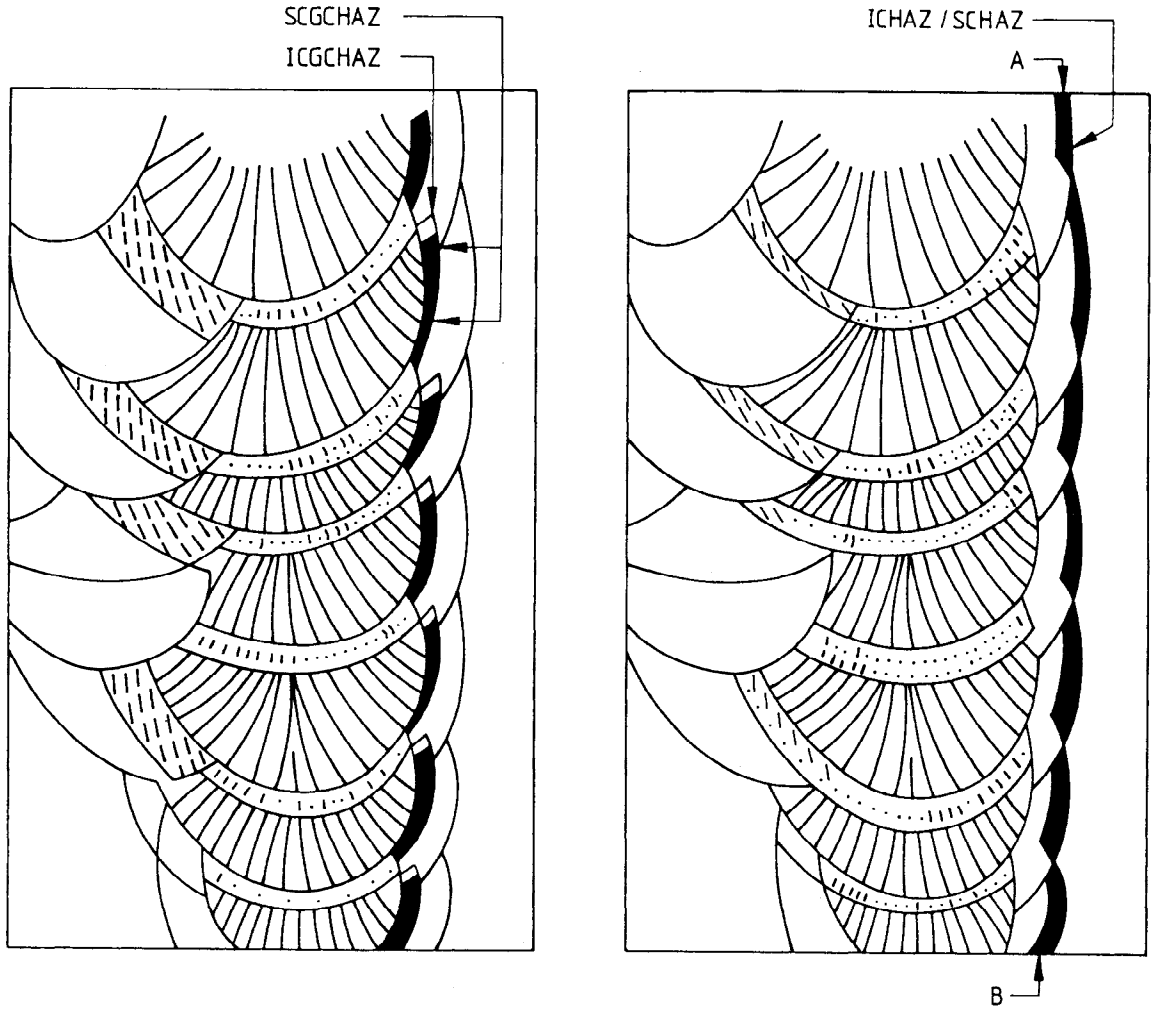
Figure 12. Vickers hardness testing for plate butt weld (see **F.4.4**)



NOTE. The abbreviations are as follows:

SCHAZ = subcritical heat-affected zone;
ICHAZ = intercritical heat-affected zone;
FGHAZ = fine grain heat-affected zone;
GCHAZ = grain-coarsened heat-affected zone.

Figure 13. The HAZ regions in a single-bevel multi-pass weld (see **F.4.3.1**)

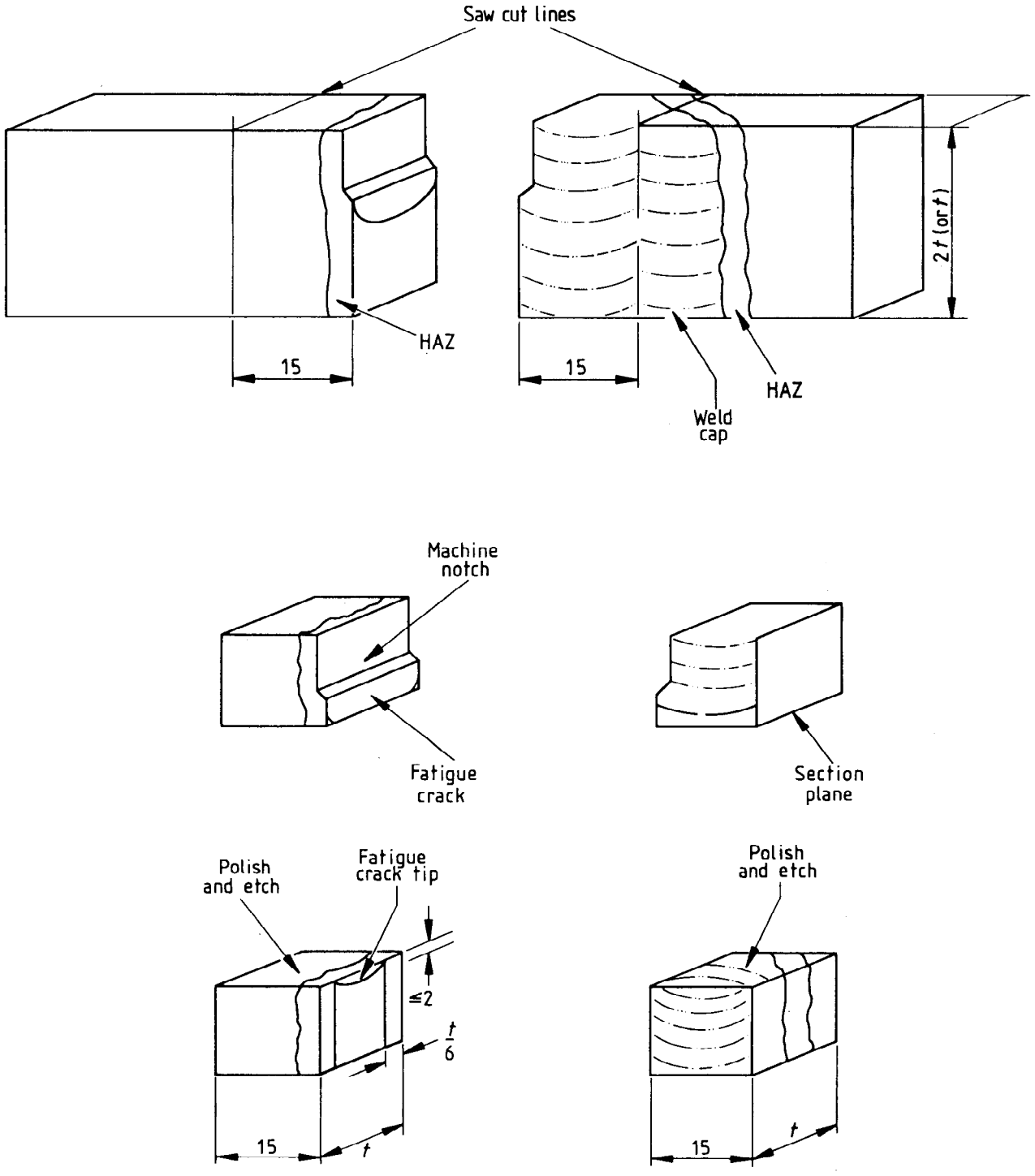


(a) Intercritically and subcritically reheated GCHAZ (ICGCHAZ and SCGCHAZ)

(b) Intercritical/subcritical HAZ boundary (ICHAZ/SCHAZ)

NOTE. A/B is the notch line.

Figure 14. The HAZ regions in a single-bevel multi-pass weld with specific zones highlighted (see **F.4.3.1**)



All dimensions are in millimetres.

NOTE. Where t is the thickness (in mm).

Figure 15. COD specimen sectioning details (see F.4.3.3)

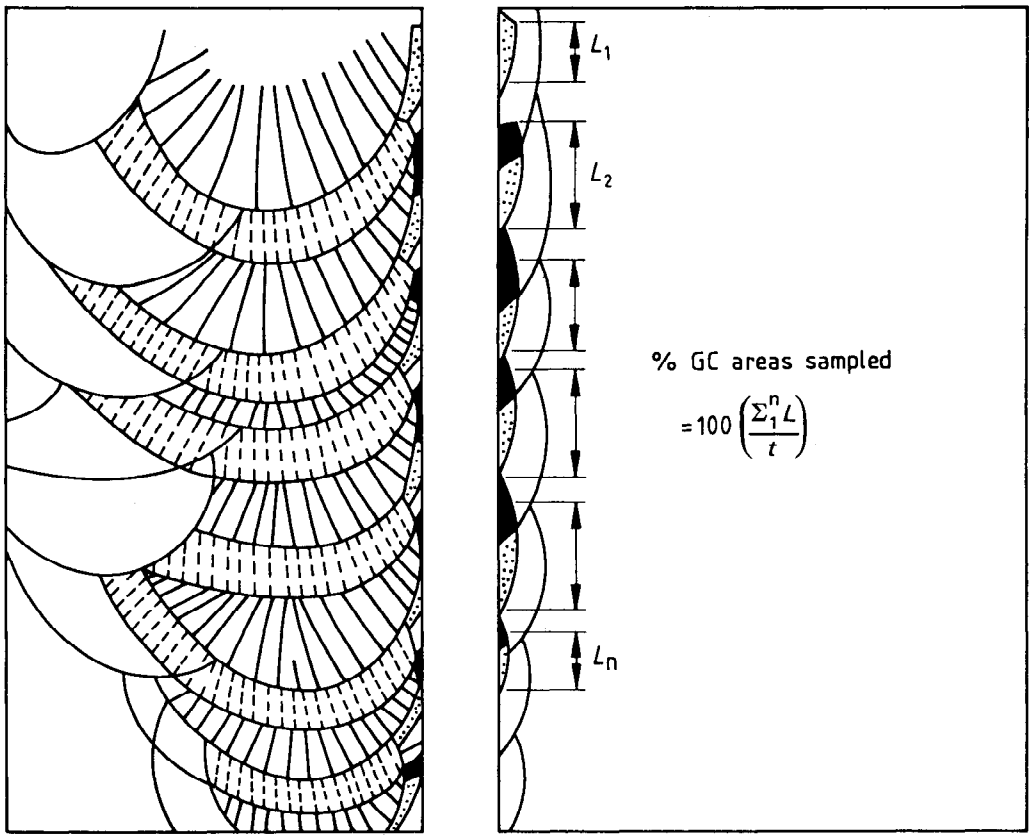


Figure 16. Plan view of polished section halves showing method to calculate GCHAZ percentage (see **F.4.3.4**)

Appendix G. Bead-on-plate weldability test for modified grades

G.1 General

The manufacturer shall carry out bead-on-plate tests and determination of HAZ hardness as follows:

(a) either as part of the programme to categorize the steel; and/or

(b) to assess the response of individual heats in terms of hardenability during welding.

The purchaser shall specify which applies.

When called for as part of the programme to categorize the steel, the tests shall be performed on the same type and thickness of plate as in appendix F. When used to assess the response in terms of hardenability of individual heats the tests shall be performed on the thickest plate rolled from each heat.

G.2 Test plate dimensions

The minimum dimensions of each test plate shall be 300 mm long and 150 mm wide.

G.3 Welding method

The welding method shall be mechanized autogenous GTAW bead-on-plate welding in accordance with table 23, the weld shall be made full length within 10 mm of the longitudinal centreline of the plate in accordance with figure 17.

Before welding, the welding line down the centre of the plate shall be cleaned of dirt and mill scale by grinding or rubbing with emery paper. The preheat shall be measured and recorded immediately before welding.

The centre of all indents should be as close as possible to, but shall be clear of the fusion line.

Table 23. Bead-on-plate arc energy and preheat conditions

Welding position	Flat
Electrode diameter (mm)	2.4
Arc voltage (V, d.c. neg.)	10 ± 0.5
Current (A)	200 ± 5
Travel speed (mm/min)	120 ± 5
Preheat: (°C maximum) thickness above 40 mm	125

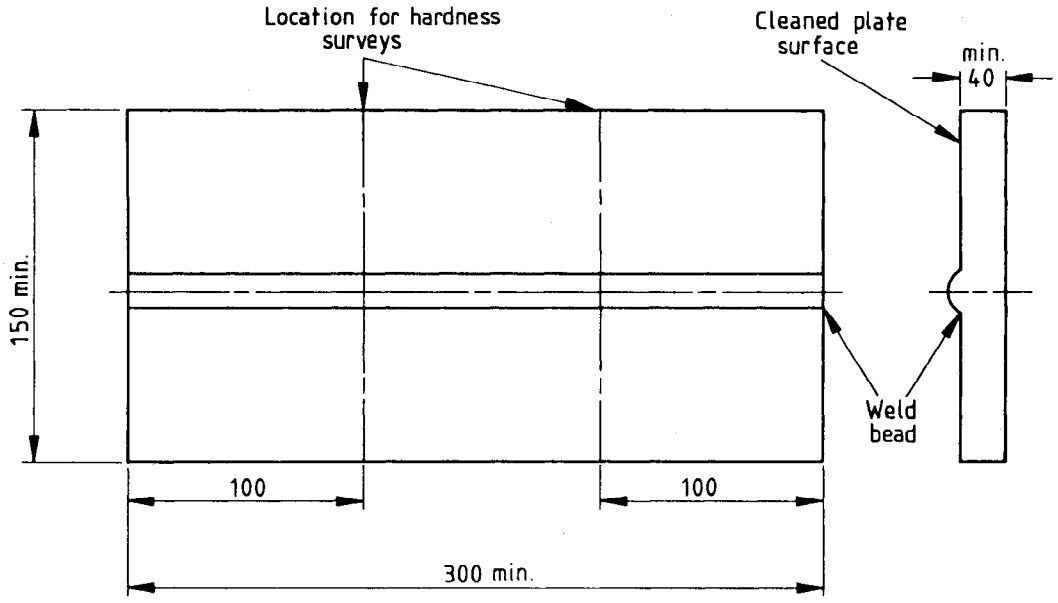
G.4 Test condition

All testing shall be carried out with the test plate in the 'as welded' condition.

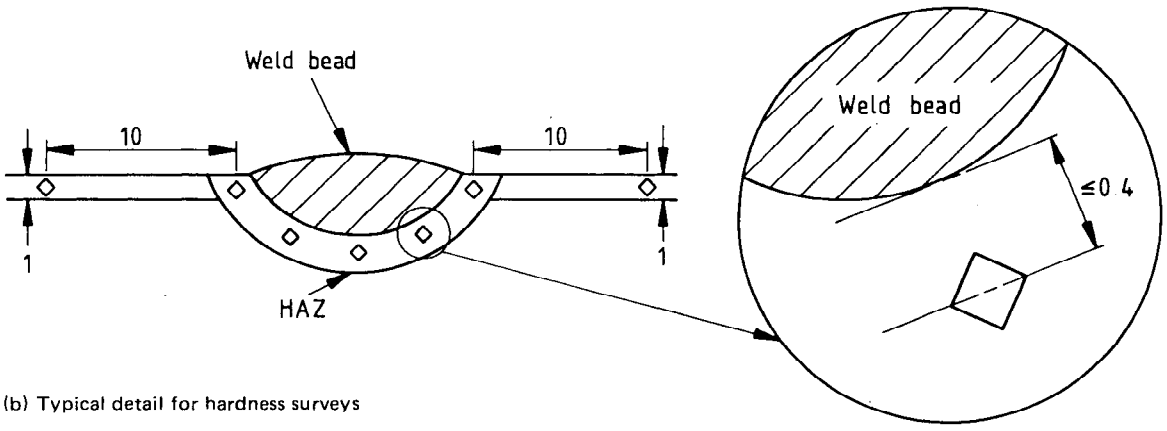
G.5 Specific test requirements

Cross sections shall be cut through the weld at 100 mm from each end of the weld. These shall be polished and etched to identify the fusion line. Vickers hardness indents shall be made in the HAZ and in the parent metal, in accordance with BS 427 : Part 1, using a 10 kg load at the locations indicated in figure 17 of this standard.

NOTE. Maximum hardness should be agreed between the manufacturer and the purchaser.



(a) Test plate



(b) Typical detail for hardness surveys

(c) Typical indent location

All dimensions are in millimetres.
NOTE. This figure is not to scale.

Figure 17. Detail of test plate and location of hardness indentation for bead-on-plate hardenability test (see **G.3** and **G.5**)

Publications referred to

BS 4	Structural steel sections
	Part 1 Specification for hot-rolled sections
BS 18	Method for tensile testing of metals (including aerospace materials)
BS 131	Methods for notched bar tests
	Part 2 The Charpy V-notch impact test on metals
BS 427	Method for Vickers hardness test
BS 1449	Steel plate, sheet and strip
	Part 1 Specification for carbon and carbon-manganese plate, sheet and strip
BS 1837	Methods for the sampling of iron, steel, permanent magnet alloys and ferro-alloys
BS 3894	Method for converting elongation values for steel
	Part 1 Carbon and low alloy steels
BS 4360	Specification for weldable structural steels
BS 4848	Specification for hot-rolled structural steel sections
	Part 2 Hollow sections
	Part 4 Equal and unequal angles
	Part 5 Bulb flats
BS 4870	Specification for approval testing of welding procedures
	Part 1 Fusion welding of steel
BS 4871	Specification for approval testing of welders working to approved welding procedures
	Part 1 Fusion welding of steel
BS 5135	Specification for the arc welding of carbon and carbon manganese steels
BS 5252	Framework for colour co-ordination for building purposes
BS 5500	Specification for unfired fusion welded pressure vessels
*BS 5750	Quality systems
BS 5762	Methods for crack opening displacement (COD) testing
BS 5996	Methods for ultrasonic testing and specifying quality grades of ferritic steel plate
BS 6200	Sampling and analysis of iron, steel and other ferrous metals
	Part 3 Methods of analysis
BS 6512	Specification for limits and repair of surface discontinuities of hot-rolled steel plates and wide flats
BS 6562	Terms used in the iron and steel industry
	Part 2 Glossary of terms used in classifying and defining steel industry products by shape and dimensions
BS 6780	Specification for through thickness reduction of area of steel plates and wide flats
Handbook 19	Methods for the sampling and analysis of iron, steel and other ferrous metals
API 5L	Specification for line pipe
CSWIP-UST-5	Requirements for the certification of personnel engaged in the manual ultrasonic testing of steel plate and rolled products
CSWIP-MAGPEN-4	Requirements for the certification of personnel engaged in magnetic particle and/or penetrant testing metallic materials, components and welded constructions
DIN 50049	Certificates on material testing

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Committees responsible for this British Standard

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British Railways Board
British Steel Industry
County Surveyors' Society
Department of the Environment (Construction Industries Directorate)
Department of Transport
Electricity Supply Industry in England and Wales
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Lloyds Register of Shipping
London Regional Transport
National Association of Steel Stockholders
North East Coast Institution of Engineers and Shipbuilders
Society of Motor Manufacturers and Traders Limited
Steel Construction Institute
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