BSI BS*7363 90 ■ 1624669 0210880 1 ■

Methods for

Controlled thermal severity (CTS) test and bead-on-plate (BOP) test for welds

Méthodes d'essai des soudures: essai de fissuration (essai CTS) et essai de dureté sous cordon (essai BOP)

Kontrollierte Wärmeableitungsprüfung und RaupenaufschweiBprüfung bei SchweiBnähten

BSI STANDARDS

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Welding Standards Policy Committee (WEE/-) to Technical Committee WEE/2, upon which the following bodies were represented:

Aluminium Federation
Associated Offices Technical Committee
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Welding Manufacturers' Association (BEAMA Ltd.)

This British Standard, having been prepared under the direction of the Welding Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 30 November 1990

The following BSI references relate to the work on this standard:
Committee reference WEE/2
Draft for comment 89/75604 DC

ISBN 0 580 18963 5

Amendments issued since publication

Amd. No.	Date	Text affected

Contents

Foreword

This British Standard has been prepared under the direction of the Welding Standards Policy Committee. The CTS test is used for determining the extent of susceptibility to weld heat affected zone (HAZ) hydrogen cracking and the BOP test is used to investigate weld HAZ hardening behaviour.

Tests are normally performed for the evaluation of parent material characteristics. Tests may also be used to investigate welding consumables and welding parameters.

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

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

Section 1. General

1.1 Scope

This British Standard describes the controlled thermal severity (CTS) test and the bead-on-plate (BOP) test for welds. These are intended for investigating the welding of carbon, carbon-manganese and low-alloy steels.

Tests are normally performed for the evaluation of parent material characteristics. Tests may also be used to investigate welding consumables and welding parameters. Although the CTS test is principally intended for the manual metal arc welding process, its use for other processes is not precluded, provided that the test is in accordance with this standard.

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

1.2 Definitions

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

1.3 Measurements

Knowledge of the correct values of the variables involved in producing test welds is vital to the success of the tests and calibrated measurement devices shall be used. The values of these measured variables shall be noted on the test report sheet (TRS).

NOTE. It is recommended that traceability to national standards of calibration is maintained.

An individual test involves many variables, particularly in relation to the materials used, and all the data characterizing the specific test shall therefore be recorded as failure to do this could result in misinterpretation of results.

A list of the required variables appears in the relevant TRS (see examples given in appendices A and B).

1.4 Material for test pieces

The material for the tests shall be in the metallurgical condition in which it will be welded.

Where the material to be used is identified by a cast number, this shall be noted in the TRS. Where the principal rolling direction can be determined, this shall be marked on the test material by hard stamping remote from the weld testing area.

The chemical composition of the material to be tested shall be available. When the test is being performed for material release purposes the product analysis certificate shall be acceptable. In all other circumstances the chemical analysis shall be performed on the material to be tested and the elements to be determined shall be as follows:

carbon
silicon
manganese
phosphorus
sulphur
chromium
molybdenum
nickel
vanadium
copper
niobium
calcium
boron
titanium
aluminium
nitrogen

In selecting the technique for analysis and the areas for sampling, care shall be taken to provide average values of elements and to avoid localized effects in the material caused by segregation and surface decarburization. The results and the analytical tolerances shall be entered on the TRS as mass percentages.

NOTE. It is considered good practice to confirm the accuracy of the analytical technique against certified reference materials.

Section 2. CTS test

2.1 Application

A CTS test piece consists of two blocks (top and bottom) with two anchor welds and two test welds (see figure 1). The CTS test provides a means of assessing the susceptibility of steels to HAZ hydrogen cracking and also for assessing means of avoiding HAZ hydrogen cracking. One individual test gives one result, i.e. 'Cracked' or 'Not cracked'.

It is frequently necessary to perform an investigation consisting of a series of tests to define the crack/no crack boundary and therefore the limits of weldability for the specific material or welding consumables being investigated. Variables that define a crack/no crack boundary are arc energy, preheat, weld metal hydrogen levels and the combined thickness of the joint.

2.2 Number of tests

2.2.1 Single tests

Where a fixed set of welding conditions is being used on a specific material, both test welds shall be made with these same welding conditions and both shall be evaluated.

2.2.2 Crack/no crack boundary determinations

Where a series of tests is to be used to obtain a crack/no crack boundary criteria the uncracked test apparently defining the boundary shall be repeated. If this test also gives an uncracked result no further testing shall be required. If cracking is observed in the duplicate test further tests shall be performed to define the boundary.

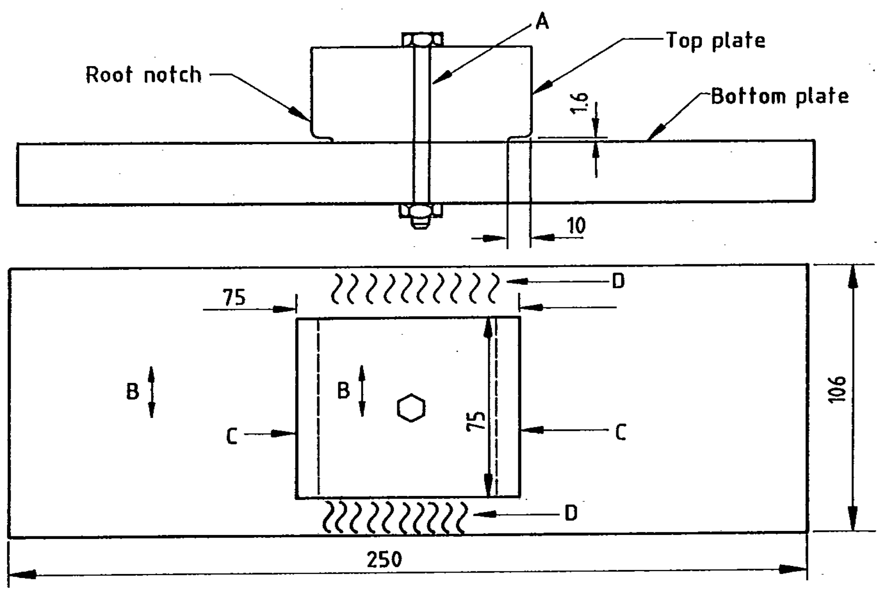
NOTE 1. Where arc energy is the variable it is preferred that the boundary is defined to within 0.3 kJ/mm and that the duplicate tests are carried out to within ± 0.1 kJ/mm.

NOTE 2. Where preheat is the variable it is preferred that the boundary is defined to within 25 °C.

2.3 Machining of test plates

Machine the test material for the test pieces by sawing, milling or grinding. Ensure that surfaces to be welded are milled or ground finish. Take care to minimize heating and deformation in the material during machining.

Use the general arrangement of the test piece shown in figure 1 and the tolerances and surface finish requirements given in table 1.



All dimensions are in millimetres.

Key
A Clearance hole 13 mm diameter
B Preferred principal rolling direction
C Test welds
D Anchor welds

Figure 1. CTS test

Table 1. CTS test piece dimensions/conditions and tolerances

Dimension/conditions	Value
Material thickness, *t*	6 mm min.
Top block	75 ± 1 mm × 75 ± 1 mm × *t*
Bottom block	250 ± 3 mm × 100 ± 3 mm × *t*
Root notch width	10 ± 0.5 mm
Root notch depth	1.6 ± 0.10 mm
Torque on bolt	100 ± 5 N·m
Surface finish on mating faces	3.2 μm R_a max.
Surface finish on area to be welded	6.3 μm R_a max.
Mating face gap	0.05 mm max.

Use top and bottom blocks that both have the same thickness and are machined from the same material. In those exceptional circumstances where it is impossible to machine both blocks from the test material, machine the top block from the material under test and machine the bottom block from a material of equivalent yield strength. Ensure that the susceptibility of the bottom block to HAZ hydrogen cracking is less than that of the test material. Enter the reasons for not using the test material for both blocks on the TRS.

Where the principal rolling direction of the plate can be determined, arrange the rolling directions of the top and bottom plates to be the same (see figure 1).

Ensure that the surfaces to be welded and to be used for the current return lead attachment are ground smooth and free from scale, rust, oil, grease and other contaminants.

Use a bolt with a 12 mm diameter for assembling the blocks. Degrease the bolt, a suitable plain nut and any washers to be used prior to use. Do not use nuts and bolts treated by plating processes. Insert the bolt through the top and bottom blocks, add the nut and washers and tighten to the required torque (see table 1). Check the torque value prior to all welding operations and adjust as necessary.

2.4 General welding details

Where applicable, perform welding in accordance with BS 5135.

2.5 Anchor welds

Make the anchor welds (shown in figure 1) with a welding consumable with a yield strength (as determined using the test piece described in appendix D of BS 639 : 1986) equal to or greater than the yield strength of the material under test, up to a parent material yield strength of 895 N/mm^2.

NOTE. Where the yield strength of the parent material exceeds 895 N/mm^2, the consumable selected may have a yield strength less than that of the parent material (but greater than 895 N/mm^2) or austenitic stainless steel weld deposits may be used.

Start and finish the anchor fillet welds 10 mm (± 3 mm) from the corners of the top plate and make them with the following throat sizes:

up to 15 mm plate thickness 6 ± 1 mm

plate thickness 15 mm and over 13 ± 1 mm.

Deposit the welds with a procedure to avoid hydrogen cracking, using preheat, interpass and post-heating control as necessary.

Dry all consumables used for anchor welds in accordance with manufacturers' recommendations to give the lowest possible hydrogen levels. Record details on the TRS.

Check the torque on the bolt and tighten the bolt where necessary. Leave the assembly for 12 h before further welding.

2.6 Test welds

2.6.1 Preheat

When the test requires a preheat, place the assembly in an oven and leave it for sufficient time to ensure even and thorough heating. Set the oven at a higher temperature than required for the test in order to allow for the cooling of the assembly during transfer and set-up.

Prior to any welding, check the temperature of the test blocks using a calibrated surface pyrometer. Where the test demands a specific temperature of preheat, do not commence welding until the required temperature is achieved. Ensure that the temperatures of the top and bottom blocks in the test area do not differ by more than 5 °C.

Record the temperatures on the TRS.

2.6.2 Deposition

Use a jig to position the assembly and check the correct alignment of the electrode/wire with respect to the test block (see figure 2).

Deposit the test welds in the flat position across the full width of the block in a single direction and in a single pass. Ensure that the test weld does not extend beyond the ends of the block.

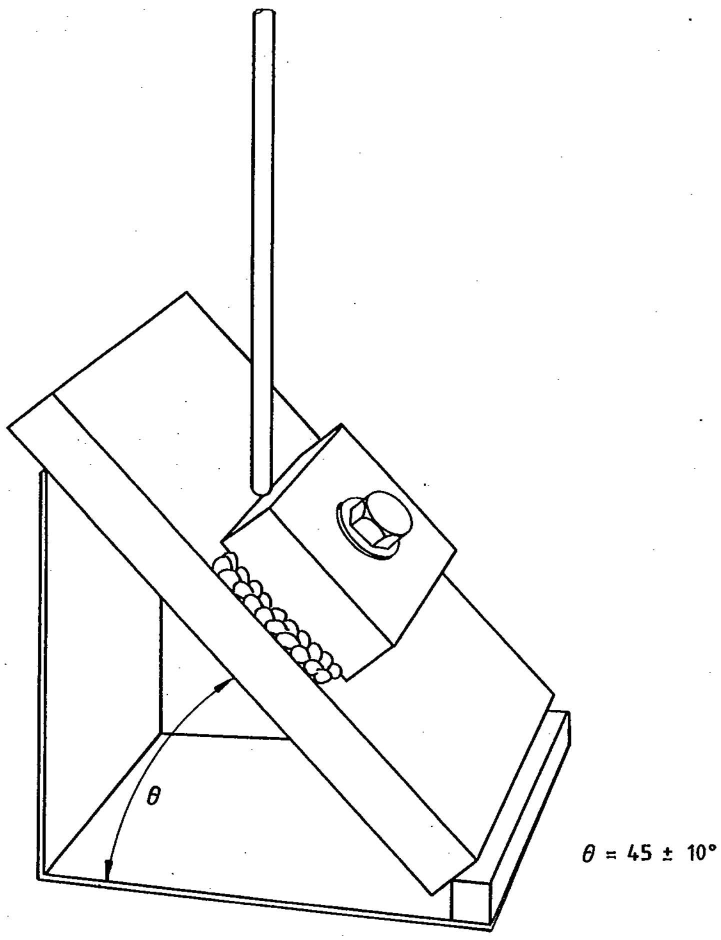


Figure 2. Jig used to position test assembly

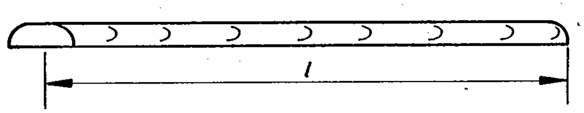


Figure 3. Measurement of weld length, *l*

Calculate the welding speed as weld length, l (in mm), divided by the welding time, s (in s). Determine the weld length by measuring from the start of the weld to the centre of the weld crater as shown in figure 3.

Measure the welding current, I (in A), welding voltage, V (in V), and welding speed, W (in mm/s), and calculate the value of arc energy (in kJ/mm) using the following equation:

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

NOTE 1. When coated manual metal-arc welding electrodes are used for producing the CTS test welds, sometimes they are not treated in accordance with manufacturers' recommendations. The treatments applied in these cases, if any, should be noted on the TRS.

NOTE 2. Manual welding is difficult to control and monitor adequately. It is therefore recommended that mechanized deposition equipment is used.

NOTE 3. In view of the short length of the test weld deposit, care has to be taken in measuring the weld length and welding time accurately to achieve reliable and accurate results of welding speed.

NOTE 4. Arc efficiency varies according to the process and this can be allowed for when comparing tests made by different processes as detailed in BS 5135.

2.6.3 Post-heating

Where post-heating is required, transfer the assembly to an oven immediately following the completion of welding.

Monitor post-heating by thermocouples or equivalent devices on the test blocks.

2.6.4 Cooling

Following deposition of the first test weld bead and after any post-heating treatment, transfer the test assembly to a cooling bath whereby the end of the assembly opposite the welded end is immersed in cold flowing water to a depth of 60 ± 5 mm (see figure 4). Complete transfer to the bath within 60 s of the completion of welding (or post-heating, where applied). Ensure that the water temperature at the exit of the cooling bath does not exceed 30 °C during the test.

2.6.5 Deposition of the second weld

Keep the assembly in the bath until the temperature has fallen to ambient and then remove it. Leave it for a further 72 h (minimum) before depositing the second weld in accordance with **2.6.2**.

Following cooling of the second test weld, leave the assembly for 72 h (minimum) before proceeding with further work.

2.6.6 Hydrogen determination

Measure the diffusible hydrogen content of the consumable (in mL per 100 g deposited metal) using the technique and test piece described in the relevant Part of BS 6693 and the relevant consumable standard. Use a determination appropriate to the consumable and atmospheric conditions at the time of the CTS test.

2.7 Metallographic examination

2.7.1 Sectioning

Section the test pieces for metallurgical examination by sawing or an alternative mechanical method. Minimize heating of the material by the application of coolant. Make cuts at ¼, ½ and ¾ length positions along the bead (see figure 5).

2.7.2 Preparation and examination

Prepare the six cut faces for micro-examination in accordance with BS 709 or by an alternative electropolishing technique capable of giving equivalent or better preparation.

Examine the prepared faces of the weld metal and HAZ for cracking at a minimum magnification of × 50. Confirm the result for uncracked specimens at a suitable magnification (× 200 minimum). Examine either face 2b or 3a first (see figure 5).

2.7.3 Measurements and reporting of results

If cracking is detected, measure the length of such cracks. If individual cracks are less than 5 % of the leg length of the weld (determined as shown in figure 6), report the sample as 'Not cracked' and examine the next face.

If there are HAZ cracks longer than 5 % of the leg length, report the test weld as 'Cracked' and terminate the metallographic examination. Examine all six faces if no cracking is found.

When the bottom plate material is different to that used for the top plate (see **2.3**) and HAZ cracking is only present in the bottom plate, the test is declared invalid.

If the weld metal is found to display root cracking of total length greater than 5 % of the throat thickness, the test piece is invalid and testing of the test pieces involved is terminated.

2.8 Hardness testing

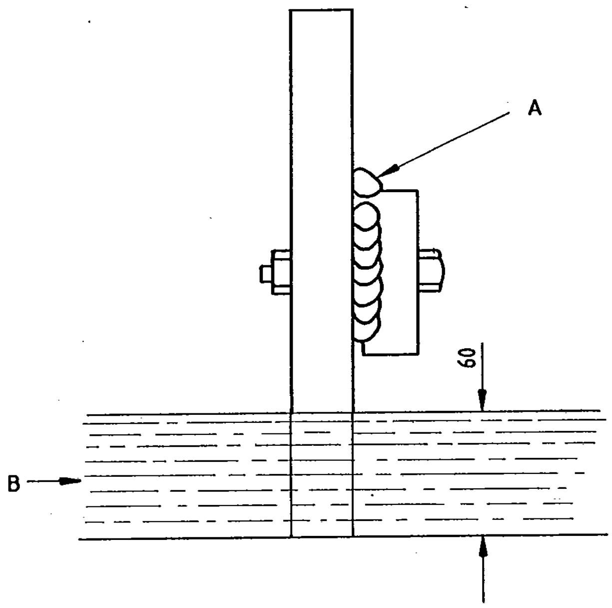
Subject one of the central faces from each test weld (face 3a or 2b in figure 5) to Vickers hardness tests in accordance with BS 427 in the positions indicated in figure 7. Select the indentation load of 2.5 kg, 5 kg or 10 kg so that the hardness impressions are contained within the grain-coarsened zone of the HAZ and such that 10 impressions can be accommodated. Discount results from HAZ hardness impressions entering the weld zone, the grain refined zone or the unaffected parent material and make a further impression.

Record the results, including the maximum, the minimum and the average values, on the TRS.

2.9 Recording of results

All details of the materials, their welding and testing shall be recorded on a TRS.

NOTE. A typical form of TRS is shown in appendix A.



Dimension is in millimetres.

Key
A Test weld
B Water

Figure 4. Cooling bath arrangement

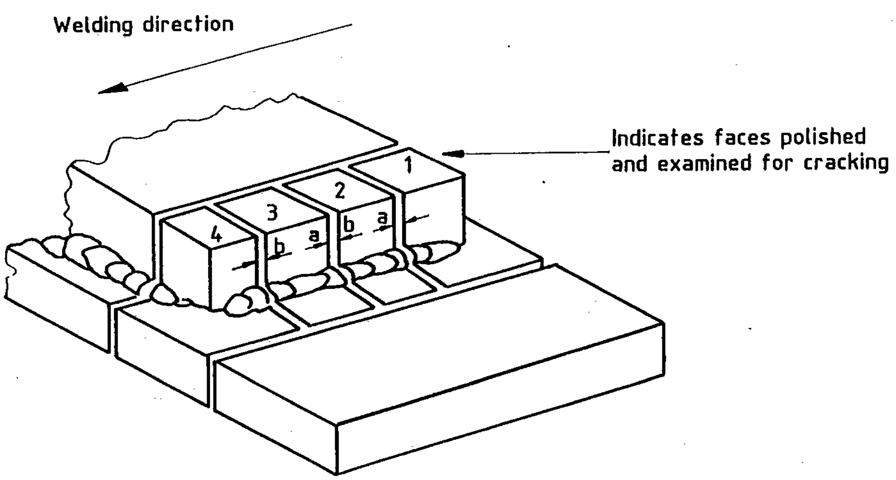
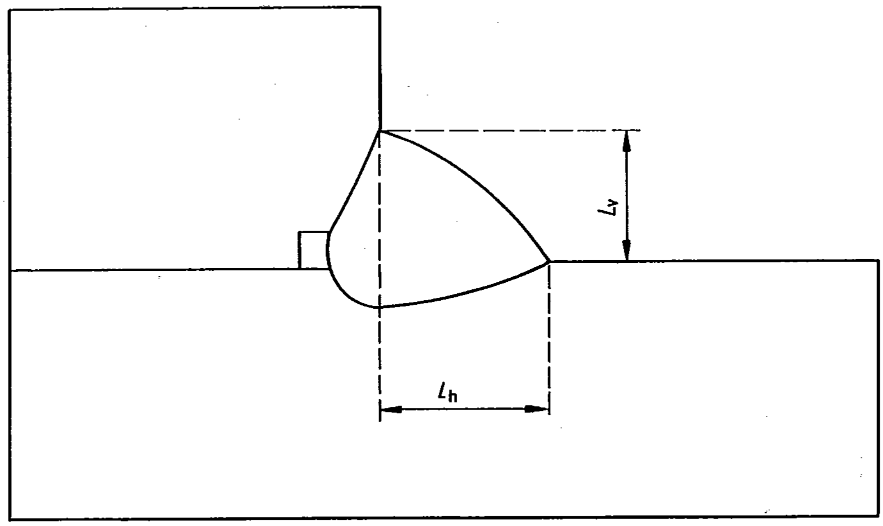
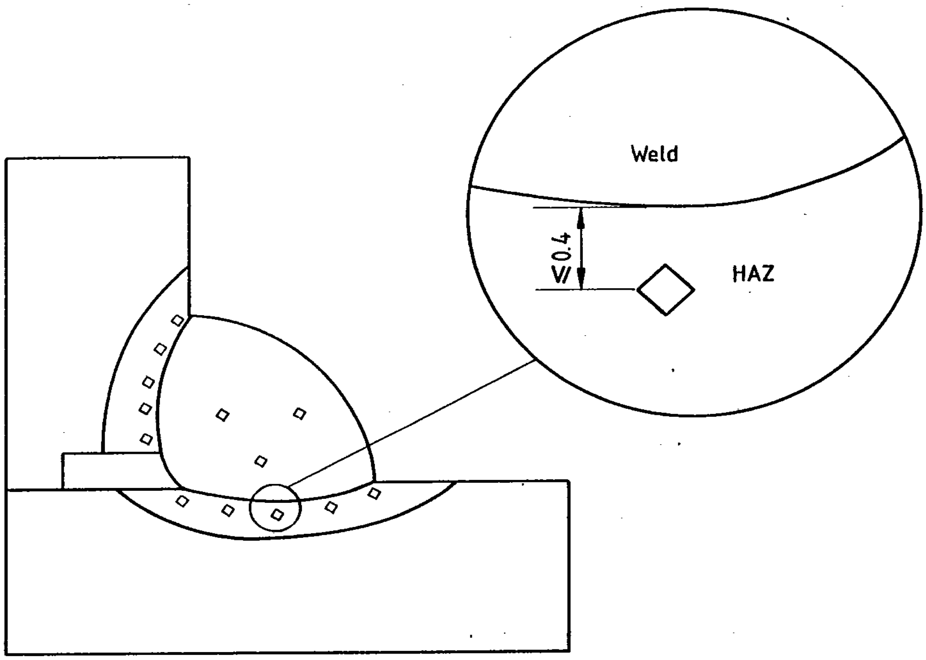


Figure 5. Sectioning of CTS test piece



Leg length = $\frac{L_v + L_h}{2}$

Figure 6. Measurement of leg length



Dimension is in millimetres.

NOTE. The distance of any indentation should be not less than that permitted by BS 427 for the previous indentation.

Figure 7. Typical positions of hardness test impressions

Section 3. BOP test

3.1 Application

The BOP test is simple to execute and evaluate. It is used to complement CTS tests in an investigation of weldability or can be used independently as a control test.

The BOP test is used solely for measuring HAZ hardness and production of a crack-free test does not give any assurance that other welds deposited in a similar manner will be crack-free.

Results from CTS tests relating hardness to cracking susceptibility can be utilized in the interpretation of BOP test results to predict potential material cracking problems.

3.2 Test piece form

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

The actual size of plate used shall be entered on the TRS.

3.3 Welding

3.3.1 General

Where applicable, perform welding in accordance with BS 5135. Where there are deviations from this standard, note these in the TRS.

3.3.2 Preparation and preheat

Ensure that the surfaces to be welded and to be used for the current return lead attachment are ground smooth and free from scale, rust, oil, grease and other contaminants.

When the test requires a preheat, place the test piece in an oven and leave it for sufficient time to ensure even and thorough heating. Set the oven at a higher temperature than required for the test in order to allow for the cooling of the assembly during transfer and set-up.

Prior to any welding, check the temperature of the test piece using a calibrated surface pyrometer. Where the test demands a specific temperature of preheat, do not commence welding until the required temperature is achieved.

Record the temperature on the TRS.

3.3.3 Test piece type

In welding the test piece, the following two deposition tests are possible.

Type 1. Standardized welding conditions for quality control purposes.

Type 2. Discretional deposition conditions for material characterization programmes.

The type of test selected shall be stated on the TRS.

3.3.4 Welding the type 1 standardized BOP test

Make a mechanized autogenous TIG bead-on-plate weld in accordance with the conditions given in table 2, the weld being full length along the longitudinal centreline of the plate as shown in figure 8.

Ensure that the minimum length of weld deposited is 280 mm.

Table 2. Welding conditions for the standardized BOP test

Condition	Value
Welding position	Flat
Electrode diameter (mm)	2.4
Arc voltage (V) (d.c. negative)	10 ± 0.5
Current (A)	200 ± 5
Travel speed (mm/min)	120 ± 5
Nominal arc energy (kJ/mm)	1*
Preheat (max.) (°C)	
thickness below 20 mm	None
thickness 20 mm to 25 mm	75
thickness 26 mm to 30 mm	100
thickness above 30 mm	125

* See note 4 to **2.6.2**.

3.3.5 Welding the type 2, discretional welding conditions BOP test

Detail the welding process and conditions selected in the TRS. Produce separate TRS sheets for each weld made and individually identify the sheets to each test weld.

3.3.6 Cooling of the test piece

Following welding, allow the test plate to cool naturally in still air.

3.4 Hardness testing

Section the bead transversely and polish and etch the two faces (as shown in figure 8) in accordance with BS 709 or by an alternative electropolishing technique capable of giving an equivalent or better preparation.

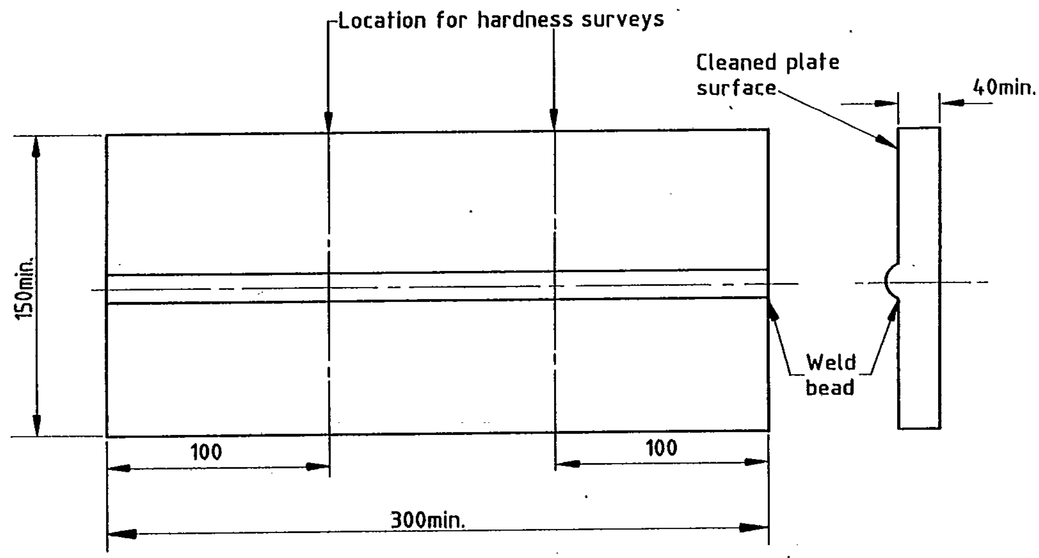
Subject these prepared faces to a Vickers hardness test in accordance with BS 427 in the positions indicated in figure 9. Select the indentation load of 2.5 kg, 5 kg or 10 kg so that the hardness impressions are contained within the grain-coarsened zone of the HAZ and such that five impressions may be accommodated. Discount results from HAZ hardness impressions entering the weld zone, the grain refined zone or the unaffected parent material and make further impressions.

Record the results, including the maximum, the minimum and the average values, on the TRS.

3.5 Recording of results

All details of the materials, their welding and testing shall be presented on a TRS.

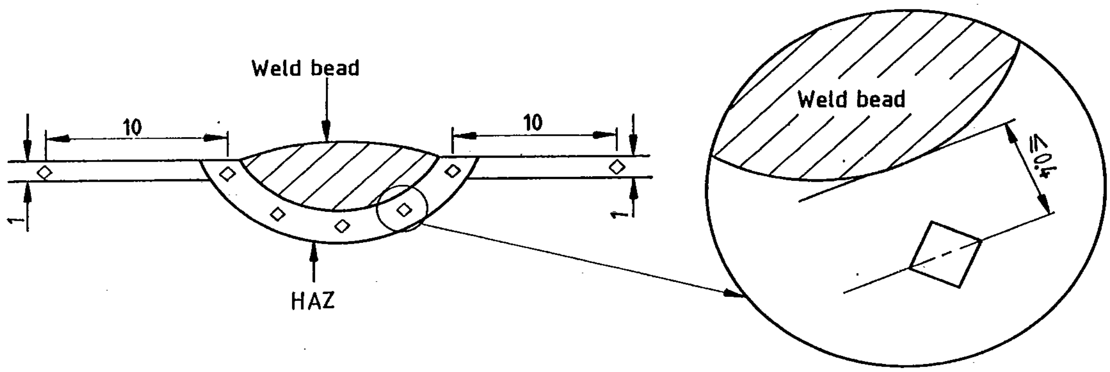
NOTE. A typical form of TRS is shown in appendix B.



Dimensions are in millimetres.

Weld bead to be full length and within 10 mm of centre of test plate.

Figure 8. Details of test plate and sectioning for BOP test



Dimensions are in millimetres.

NOTE. The distance of any indentation should be not less than that permitted by BS 427 for the previous indentation

Figure 9. Location of hardness impressions for BOP test

Appendices

Appendix A. Typical TRS for CTS test

CTS test — Test record sheet

Description of investigation	Date
	Test no.

Cast no. — Material thickness, mm:
Other details — Rolling direction indicated: Y / N

Composition					
	C %	Si %	Mn %	P %	S %
	Cr %	Mo %	Ni %	V %	Cu %
	Nb %	Ca %	B %	Ti %	Al %
	N %				

Welding details — Process

Parameters	Test weld	Welding consumable	Anchor weld	Test weld
Electrode/Wire dia.		Specification		
Amperage		Classification		
Voltage		Shielding gas/flux		
Polarity		Baking treatment		
Travel speed		Preheat temperature		
Gas type		Interpass temperature (max.)		
Gas flow rate L/min		Post-heat temperature		
Arc energy		Measuring method		

Hydrogen determination — Date
Method — Result

Metallurgical examination / Hardness testing

Section and pace	Metallurgical examination		Hardness, HV__		
	Mean leg L mm	Result (C or NC)	HAZ*	Weld metal	Parent metal

C = Cracked NC = Not cracked * Hardness = $\frac{\text{Max. value: Min. value}}{\text{Average value}}$

Conclusion: Cracked / Not cracked Signature

Appendix B. Typical TRS for BOP test

BOP test — Test record sheet						
Description of investigation					Date	
Type of test					Test no.	
Cast no.			Material thickness, mm			
Other details			Rolling direction indicated		Y / N	
Composition	C %	Si %	Mn %	P %	S %	
	Cr %	Mo %	Ni %	V %	Cu %	
	Nb %	Ca %	B %	Ti %	Al %	
	N %					

Welding details		Process
Parameters		Welding consumable
Electrode/Wire dia.		Specification
Amperage		Classification
Voltage		Shielding gas/flux
Polarity		Baking treatment
Travel speed		Preheat temperature
Gas type		Interpass temperature (max.)
Gas flow rate L/min		Post-heat temperature
Arc energy		Measuring method

Metallurgical examination/Hardness testing

Section and pace	Hardness test results, HV__			Comments
	HAZ*	Weld metal	Parent metal	

$$\text{* Hardness} = \frac{\text{Max. value: Min. value}}{\text{Average value}}$$

Signature

Publication(s) referred to

BS 427	Method for Vickers hardness test Part 1 Testing of metals Part 2 Verification of the testing machine
BS 499	Welding terms and symbols Part 1 Glossary for welding, brazing and thermal cutting
BS 639	Specification for covered carbon and carbon manganese steel electrodes for manual metal-arc welding
BS 709	Methods of destructive testing fusion welded joints and weld metal in steel
BS 5135	Specification for process of arc welding of carbon and carbon manganese steels
BS 6693	Diffusible hydrogen Part 1 Method for determination of hydrogen in manual metal-arc weld metal using 3 day collection Part 2 Method for determination of hydrogen in manual metal-arc weld metal Part 3 Primary method for the determination of diffusible hydrogen in manual metal-arc ferritic steel weld metal Part 4 Primary method for the determination of diffusible hydrogen in submerged-arc ferritic steel weld metal Part 5 Primary method for the determination of diffusible hydrogen in MIG, MAG, TIG or cored electrode ferritic steel weld metal

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