Materials and Qualification Procedures for Ships

Book A

Procedure 0-3

Guidelines for Weldability Tests for Normal and High Strength Steel

Revision 6, September 2017
Guidelines for Weldability Tests for Normal and High Strength Steel

1 General Information

1.1 Scope of The Approval

1.1.1 The weldability tests set out in this document are to be carried out as required by MQPS 3-1, 3-2 and 3-3. The tests are:

(a) Bead-on-plate tests for hardness assessment
(b) Butt weld tests.

The bead-on-plate testing is for evaluation of the effect of short arc strikes in producing high local hardness. As high local hardness could cause embrittlement of high strength steels, the requirement for this testing would be restricted to higher strength steel grades of Chapter 3, Section 3 and Section 10 of LR Rules for Materials.

The specific weldability test requirements for EH47 plate are given in Appendix 1.

The specific weldability test requirements for materials included in Chapter 3 Section 10 are given in Appendix 2.

1.2 Related Documents

1.2.1 Lloyd’s Register’s Rules and Regulations for the Classification of Ships (hereinafter referred to as the Rules for Ships).

1.2.2 Lloyd’s Register’s Rules for the Manufacture, Testing and Certification of Materials (herein referred to as the Rules for Materials).
2 Test Procedures

2.1 General

2.1.1 With regard to sample selection, when the permitted carbon equivalent value (CEV), or the maximum CEV of the agreed aim specification, is less than 0.41%, the material selected for the weldability evaluation is to have the typical CEV. If the permitted carbon equivalent, or the maximum CEV of the agreed aim specification, is more than 0.41%, the material selected for the weldability evaluation should have a CEV within 0.025% of the maximum permitted by the specification. For example, if the aim chemistry of the grade to be approved has a maximum CEV of 0.45%, then the plate to be tested according to this procedure should have a CEV of not less than 0.425%.

2.1.3 The material selected for the weldability evaluation is to be in the specified condition of heat treatment.

2.1.4 Welding consumables for butt weld assembly are to match the grade and mechanical properties of the base material and are to be selected according to the Rules for Materials, Chapter 11.

2.2 Bead-on-plate Test

2.2.1 Bead-on plate testing is not required unless indicated otherwise in the relevant MQPS for steel product manufacturer approval.

2.2.2 The tests are to be carried out on plate representing the maximum thickness for which approval is required.

2.2.3 Each test sample is to have a minimum length of 300mm and a minimum width of 150 mm.

2.2.4 The bead-on-plate weld is to be made using an automatic autogenous (i.e. no filler material) GTAW welding procedure which includes the following conditions:

(a) Welding position Flat
(b) Tungsten electrode diameter 2.4 mm
(c) Arc voltage 10 ± 0.5 V
(d) Polarity DCEN (Straight)
(e) Current 200 ± 5 A
(f) Travel speed 120 ± 5 mm/min
2.2.5 All testing is to be carried out on the welded samples in the as welded condition.

2.2.6 Cross-sections are to be cut through the weld at 100 mm from each of its ends, as shown in Fig. 0-3.3.1(a). The sections are to be polished and etched to allow the hardness test machine operator to identify the fusion line, the heat affected zone (HAZ), and the grain coarsened region of the heat affected zone (GCHAZ). Vickers hardness indentations are to be made using a maximum of 10 kg indenting load. The load actually used to make valid indentations shall be chosen so that the diagonal measurement of the indentation does not exceed 0.25 mm (normally an ocular reading of 250). Valid indentations will also be located entirely within the 0.5 mm wide GCHAZ adjacent to the fusion line as indicated in Fig. 0-3.3.1(b).

2.2.7 A minimum of five valid hardness indentations are to be reported for each cross-section. The report is to show the indentation sizes, the indenting load and the interpreted hardness value (HV) for each identified section. For each section, the average of the three highest values is also to be reported.

2.2.8 The reported average hardness values are not to exceed 380 HV for steels with a specified minimum yield strength up to H40 grades, nor exceed 420 HV for steels for H47 grades.

2.3 Tests on Butt Welds

2.3.1 Butt weld assemblies are to be welded with the following welding parameters:

(a) A fully mechanised (automatic) multi-run weld using welding conditions to give a calculated heat input (sometimes referred to as the ‘Arc Energy’) of 15 kJ/cm ± 1 kJ/cm.

(b) A full mechanised (automatic) multi-run weld with welding conditions to give a calculated heat input of 50 kJ/cm ± 2 kJ/cm.

Where a steel is required to be approved for use with heat inputs in excess of 50 kJ/cm, then the following applies in addition or in place of paragraph (b) above as agreed prior to commencement of testing;

(c) A full mechanised (automatic) weld with welding conditions to give a calculated heat input rate equal to the maximum to be approved.

The heat input, E, is to be calculated using the following formula:
\[ E = \left( \frac{V \times I \times 60}{W} \right) \times 10^3 \text{ kJ/cm} \]

Where

\[ V = \text{arc voltage, in volts} \]
\[ I = \text{welding current, in amperes} \]
\[ W = \text{welding travel speed, in cm/min} \]

WPS and/or welding records are to be submitted for review.

2.3.2 The welds are to be made in accordance with normal fabrication practices, but a square edge preparation is to be used for one side of the joint preparation. The test assemblies are to be prepared with regard to the plate rolling direction as set out in Chapter 12 Section 2.3. of LR Rules for Materials.

The individual beads are to be carefully placed so as to create a sequence of overlapping heat affected zones in which more than 15 per cent of the total grain coarsened area along the square edge side of the joint consists of un-reheated (non-tempered) microstructure.

2.3.3 If the product is intended to be used in both the as welded and post-weld stress relief heat treated (PWSRHT) conditions, test weld sets are to be made and tested in both conditions. If PWSRHT samples are not submitted, then the approval would be stated to be for as-welded condition only.

2.3.4 The butt weld tests are to include at least one cross weld tensile, Charpy V-notch (CVN) impact tests, hardness tests HV5 and photo-macrographs of the weld cross section representing each assembly.

2.3.5 The test sample locations of CVN specimens for each welded assembly are based on those described in LR Materials Rules Chapter 12, Section 2.7.8, with the butt weld having a square edge as shown in Figure 0-3.3.2. Test specimens for weld metal are not required. The cutting of each assembly to prepare the individual test specimens can use any technique, provided that any thermal cutting is at least 20 mm from the position of any finished specimen.

2.3.6 The hardness survey on each sample is to follow the requirements of 2.2.5 and 2.2.6 except in respect of the location and number of indentations to be made, and their reporting. Fig 0-3.3.3 shows how the indentations are to be placed adjacent to the weld beads at the toes of the butt welds. For each butt weld cross-section, there are to be at least three valid indentations in the GCHAZ adjacent to each of the four toe positions. The results for each toe position are to be grouped, and the highest value in each group is to be highlighted. The location of each group reported is to
be identified.

2.3.7 The highlighted hardness values are not to exceed the values specified in Chapter 12 Section 2.12.6 of the LR Rules for Materials.

2.3.8 The CVN test temperature to be used is the material grade test temperature as given in the Rules for Materials, Chapter 12, Table 12.2.2.

2.3.9 Where CTOD tests are required, specimen is to be prepared from the GCHAZ*(Grain coarsened heat affected zone), as shown in the assembly in Fig. 0-3.3.4. Each position is taken with respect of the square edge side of the joint. Three specimens are to be prepared from each position. (*The GCHAZ area is normally next to the fusion line into the parent metal and its width depends on the used welding heat input. The exact location of GCHAZ should be identified on the test specimens by polishing, etching and metallographic examination as appropriate.)

2.3.10 Each CTOD specimen is to be tested at -10°C using the procedure given in Chapter 2, Section 6 of the LR Rules for Materials. The results are to be reported in detail, showing all specimen and test measurements. Individual calculated CTOD values reported are to be not less than 0.15 mm.

2.3.11 CTOD specimens for Ni based alloys should be tested at the minimum design temperature as shown in Rules for Materials, Chapter 3, Section 6 Figure 3.6.2.

Fig.0-3.3.1(a) Test plate details for bead-on-plate welds

Fig. 0-3.3.1(a)
Test plate details for bead-on-plate welds.
T represents the maximum plate thickness for which approval is required (see 3.2.2)
Fig. 0-3.3.1(b)
Example showing location of hardness indentations on bead-on-plate welds

Fig. 0-3.3.2
Schematic diagrams showing location of Charpy V-notch impact specimens

Notch locations:
- a: on fusion line FL
- b: in HAZ, 2mm from fusion line
- c: in HAZ, 5mm from fusion line (for heat input > 50kJ/cm)
- d: in HAZ, 10mm from fusion line (for heat input > 200kJ/cm)

(a) Location of V-notch in single V butt weld for thickness ≤ 50mm)
(b) Location of V-notch in single V butt weld for thickness >50mm

(c) Location of V-notch in double V butt weld for thickness ≤ 50mm
(d) Location of V-notch in double V butt weld for thickness >50mm

Notch locations:

a: on fusion line 'FL'
b: in HAZ, 2mm from fusion line
c: in HAZ, 5mm from fusion line (for heat input >50kJ/cm)
d: in HAZ, 10mm from fusion line (for heat input >200kJ/cm)

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Fig. 0-3.3.3
Example showing locations of hardness testing in the weld, heat affected zone and parent metal of a butt weld
Fig. 0-3.3.4
Schematic diagrams showing location of CTOD specimens. Specimens are to be taken from full thickness

(a) Location of CTOD specimens in single V butt welded sample

Notch location:

a : in GCHAZ

(b) Location of CTOD specimens in double V butt welded sample

Notch location:

a : in GCHAZ
Appendix 1

Specific Weldability tests for EH47 Plate

A1.1 Bead on plate test according to the above Sections 2.2.1 to 2.2.8

A1.2 Butt weld test according to the above Sections 2.3.1 to 2.3.7

A1.3 Charpy V-notch impact testing according to the following:

(a) A set of the specimens transverse to the weld is to be taken with the notch located at the fusion line and at a distance 2, 5 and minimum 20 mm from the fusion line. The impact test temperature shall be -40°C.

(b) A set of the specimens is to be taken from the root side of the weld with the notch located at the same position and at the same depth as for the face side. The impact test temperature shall be -40°C.

(c) At each location, impact tests are to be carried out with appropriate temperature intervals in order to demonstrate the full transition range.

A1.4 Y- shape weld crack testing (Hydrogen crack testing ) according to GB/T 4675.1-84 or JIS Z 3158. The acceptance criteria is to be that no evidence of cracking should be observed.

A1.5 CTOD testing according to the following:

(a) Where CTOD tests are required, specimen is to be prepared from the GCHAZ (Grain coarsened heat affected zone), as shown in the assembly in Fig. 0-3.3.4. Each position is taken with respect of the square edge side of the joint. Three specimens are to be prepared from each position

(b) Each CTOD specimen is to be tested at -10°C using the procedure given in Chapter 2, Section 6 of the LR Rules for Materials. The results are to be reported in detail, showing all specimen and test measurements. Individual calculated CTOD values reported are to be not less than 0.15 mm
Appendix 2

Specific Weldability tests for high strength steels

A2.1  Bead on plate test according to the above sections 2.2.1 to 2.2.7.

A2.1.1  Acceptance criteria: The maximum hardness value should not be higher than 380HV for steel grades H42 to H46, not higher than 420HV for H50 to H69, and not higher than 450HV for H89 and H96.

A2.2  Butt weld tests

A2.2.1  For H42 to H50 grade steels weldability tests are to be carried out on samples of the thickest plate.

a)  1 x butt weld test assembly welded with a heat input of 15±2 kJ/cm is to be tested as-welded.

b)  1 x butt weld test assembly welded with a heat input of 50±5kJ/cm for N/NR and TM, and 35±3.5kJ/cm for QT steels is to be tested as-welded (N-normalised, NR normalised rolled, TM thermomechanical controlled rolled, QT quenched and tempered).

c)  1 x butt weld test assembly welded with the same heat input as given in b) is to be post-weld heat treated (PWHT) prior to testing.

Note: Steels intended to be designated as steels for high heat input welding are to be tested with 1 x butt weld test assembly in the as-welded condition and 1 x test assembly in the PWHT condition, both welded with the maximum heat input being approved.

A2.2.2  For H55 to H96 grade steels weldability tests are to be carried out on the thickest plate with the highest toughness grade for each strength grade.

a)  1 x butt weld test assembly welded with a heat input 10±2 kJ/cm is to be tested as-welded.

b)  1 x butt weld test assembly welded with a maximum heat input as proposed by the Manufacturer is to be tested as-welded. The approved maximum heat input shall be stated on the approval certificate.

Note: If the Manufacturer requests to include the approval for Post Weld Heat Treat (PWHT) condition, 1 x additional butt weld test assembly welded with a maximum heat input proposed by the Manufacturer for the approval same as test assembly b) is to be post-weld heat treated (PWHT) prior to testing.
A2.3 Butt weld test assembly

The butt weld test assemblies for N/NR plates are to be prepared with the weld seam transverse to the final plate rolling direction.

The butt weld test assembly of TM/TM+AcC/TM+DQ and QT plates are to be prepared with the weld seam parallel to the final plate rolling direction. The butt weld test assemblies of long product, sections and seamless tubular in any delivery condition are to be prepared with the weld seam transverse to the rolling direction.

A2.4 The welds are to be made in accordance with normal fabrication practices, but a square edge preparation is to be used for one side of the joint preparation.

A2.5 Post-weld heat treatment procedure

a) Steels delivered in N/NR or TM/TM+AcC/TM+DQ condition shall be treated for a minimum time of 1 hour per 25 mm thickness (but not less than 30 minutes and needs not to be more than 150 minutes) at a maximum holding temperature of 580°C, unless otherwise approved at the time of approval.

b) Steels delivered in QT condition shall be heat treated for a minimum time of 1 hour per 25 mm thickness (but not less than 30 minutes and needs not to be more than 150 minutes) at a maximum holding temperature of 550°C with the holding temperature of at least 30°C below the previous tempering temperature, unless otherwise approved at the time of approval.

c) Heating and cooling above 300°C shall be carried out in a controlled manner in order to heat/cool the material uniformly. The cooling rate from the maximum holding temperature to 300°C shall not be slower than 55°C/hr.

A2.6 The butt weld tests are to include the following:

a) 1 x cross weld tensile test; 1 x full thickness test sample or sub-sized samples covering the full thickness cross section.

b) 1 x set of 3 Charpy V-notch impact specimens transverse to the weld seam based on those described in LR Materials Rules Chapter 12, Section 2.7.8 with butt weld having square edge as shown in Figure 0-3.3.2. Test specimens for weld metal are not required. The cutting of each assembly to prepare the individual test specimens can use any technique, provided that any thermal cutting is at least 20mm from the position of any finished specimen. The test temperature is to be the one prescribed for the testing of steel grade.

c) Hardness tests HV10 across the weldment. The indentations are to be made along a 1-2mm transverse line beneath the plate surface on both the face side and the roost side of the weld as follows:
- Fusion line
- HAZ: at each 0.7mm from fusion line into unaffected base material (6 to 7 mm minimum measurements for each HAZ)

The maximum hardness values should not be higher than 350Hv for grade steel H42 to H46; not be higher than 420HV for H50 to H69; and not to be higher than 450Hv for H89 and H96.

A sketch of the weld joint depicting groove dimensions, number of passes, hardness indentations should be attached to the test report together with photo-macrographs of the weld cross section representing each assembly.

d) CTOD test specimens are to be prepared from the GCHAZ* (Grain coarsened heat affected zone) as shown in the test assembly in Figure 0-3.3.4. Each position is taken with respect of the square edge side of the joint. Three specimens are to be prepared for each position.

(*The GCHAZ area is normally next to the fusion line into the parent metal and its width depends on the used welding heat input. The exact location of GCHAZ should be identified on the test specimens by polishing, etching and metallographic examination as appropriate.)

The specimen geometry (B=W) is permitted for plate thickness up to 50 mm. For plate thicker than 50 mm, subsidiary specimen geometry (50x50 mm) is permitted, which is to be taken 50 mm in depth through thickness from the subsurface and 50 mm in width.

Each CTOD specimen is to be tested at -10°C using the procedure given in Chapter 2, Section 6 of the Rules for Materials. The results are to be reported in detail, showing all specimen and test measurements. Individual calculated CTOD values reported are to be not less than 0.15 mm.

For grades H69 and above, dehydrogenation of the as welded test pieces may be carried out by a low temperature heat treatment, prior to CTOD testing. Heat treatment conditions of 200°C for 4 h are recommended and the exact parameters shall be notified with the CTOD test results.

e) Y-shape crack testing (Hydrogen crack testing) according to GB/T 4675.1-84 or JIS Z 3158. Minimum preheat temperature is to be determined and the relationship of minimum preheat temperature with thickness is to be derived. The acceptance criteria is to be that no evidence of cracking should be observed.