

No. 139 Guidelines on Approval of Hull Steels with Improved Fatigue Properties

(Feb 2015)

1. Scope

1.1 General

1.1.1 This document gives the recommended guidelines on approval of hull steels with improved fatigue properties.

1.1.2 "Hull steels with improved fatigue properties" (hereinafter called "fatigue resistant steels") in this document are defined as hull structural steels complying with the following:

- (1) The requirements for the hull structural steels of the corresponding grade specified in UR W11;
- (2) The requirements for fatigue properties specified in 2.2;
- (3) In relation to the above 1.1.2(2), the fatigue life of transverse non-load-carrying fillet welded joint and longitudinal fillet welded gusset is two (2) times longer than that of non-fatigue resistant hull structural steels at specific stress ranges corresponding to the Nf (number of cycles to failure) of 2×10^6 cycles based on the basic design S-N curve of U.K. DEn in IACS Recommendation No. 56.
- (4) The S-N curves given in 2.2 are only intended to be used for the purpose of approval of Hull Steels with Improved Fatigue Properties, and are not intended to be used for design approval purposes to determine the fatigue life of structures which utilise these steels.

1.1.3 The weldability of fatigue resistant steels is similar to those given in UR W11, therefore welding requirements specified in UR W17 "Approval of consumables for welding normal and higher strength hull structural steels" and UR W28 "Welding procedure qualification tests of steels for hull construction and marine structures" are also applied. The additional welding procedure qualification for the fatigue resistant steels may be required at the discretion of the Classification Society.

1.1.4 The approval of fatigue resistant steels with specified minimum yield strength of over 390 N/mm^2 is at the discretion of the Classification Society.

1.2 Notes related to Design Approval

1.2.1 The design approval of hull structures with fatigue resistant steels is at the discretion of the Classification Society.

2. Additional Requirements related to Fatigue Properties

2.1 Manufacturing Approval

2.1.1 Fatigue resistant steels are to be manufactured at works which have been approved by the Classification Society for the grade of steels (including the suffix) which is being supplied.

2.1.2 Manufacturing approval is to be carried out in accordance with the requirements of the Appendix A to UR W11 together with the additional requirements of the Appendix to this document.

2.2 Fatigue Properties

2.2.1 The fatigue properties of the welded joints of fatigue resistant steels (in-air environment) is to comply with the S-N curves shown in Fig. 1. The said S-N curves are represented by linear relationships between $\log(\Delta\sigma)$ and $\log(Nf)$ as follows:

$$\log(Nf) = \log(K) - m \cdot \log(\Delta\sigma)$$

where:

- Nf: Number of cycles to failure;
- K: Constant related to S-N curve, as given in Table 1;
- m: Negative inverse slope of the S-N curve, as given in Table 1;
- $\Delta\sigma$: Stress range (N/mm²).

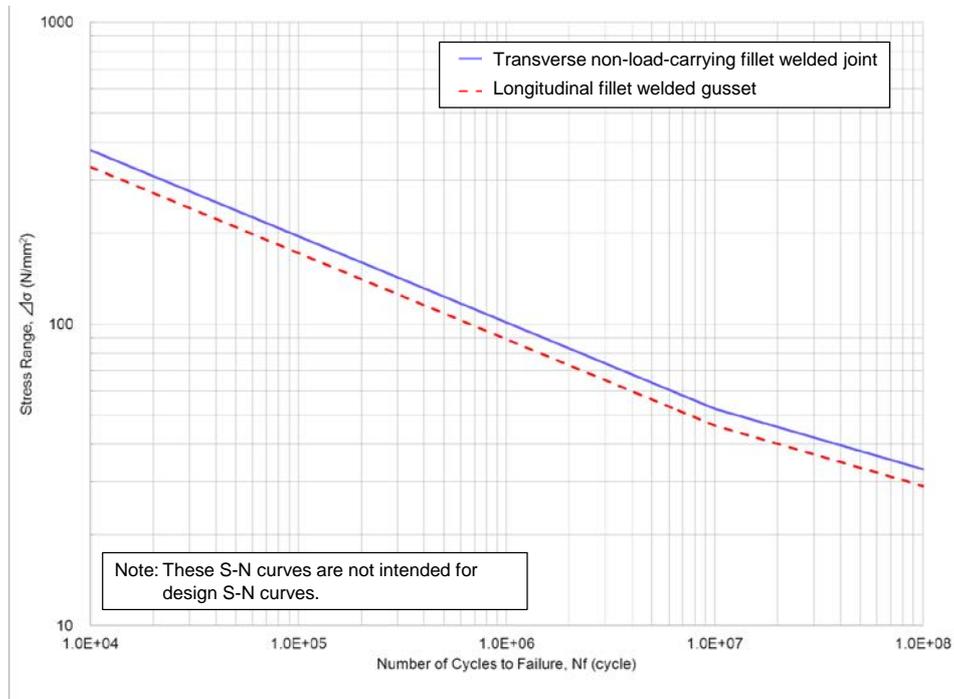


Fig. 1 Required fatigue properties (S-N curve in-air environment)

Table 1 Minimum Acceptable Parameters of S-N curve in-air environment

Kind of joints	Nf ≤ 10 ⁷		Nf > 10 ⁷	
	m	K	m	K
Transverse non-load-carrying fillet welded joint* ¹	3.5	1.0425x10 ¹³	5.0	3.9505x10 ¹⁵
Longitudinal fillet welded gusset* ²	3.5	6.6538x10 ¹²	5.0	2.0821x10 ¹⁵

Notes:

*1 Nf corresponding to $\Delta\sigma$ of 70N/mm² is 3.63x10⁶ and Nf corresponding to $\Delta\sigma$ of 150N/mm² is 2.50x10⁵ (see Table 2).

*2 Nf corresponding to $\Delta\sigma$ of 70N/mm² is 2.32x10⁶ and Nf corresponding to $\Delta\sigma$ of 150N/mm² is 1.60x10⁵ (see Table 2).

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2.2.2 The attention must be drawn to the fact that fatigue properties of welded joints are sensitive to items related to design and fabrication.

2.3 Testing and Inspection related to Fatigue Properties**2.3.1 Test Samples**

All materials in a batch presented for fatigue tests in production tests are to be of the same product form e.g. plates, flats, sections, etc. from the same cast and in the same condition of supply.

The test samples are to be fully representative of the material. In the case where off-line heat treatment such as "normalizing" and "tempering after accelerated cooling" is applied to the material, test samples shall not be cut from the test piece until the said heat treatment is completed.

The position of the samples in the width of the product is to be in accordance with UR W11.

The test specimens are to be prepared with their longitudinal axes parallel to the final direction of rolling.

2.3.2 Fatigue Test Specimens

Dimensions of fatigue test specimens are to comply with Fig. 2 in general. It is recommended that the shape of weld metal is measured by an appropriate method before testing, and its representative values and/or measured values are to be included in the test report. For steels of over 22mm in thickness, thickness of the test specimens should be reduced to 22mm from one surface. In the case where the thickness of the fatigue test specimens are reduced, it is recommended to carry out grinding on the reduced side in order to prevent the fatigue crack initiation from the reduced side.

Welding consumables approved by the Classification Society are to be used. The welding consumables which could improve the fatigue properties of welded joints (e.g. Low Transformation Temperature welding consumable) shall not be used.

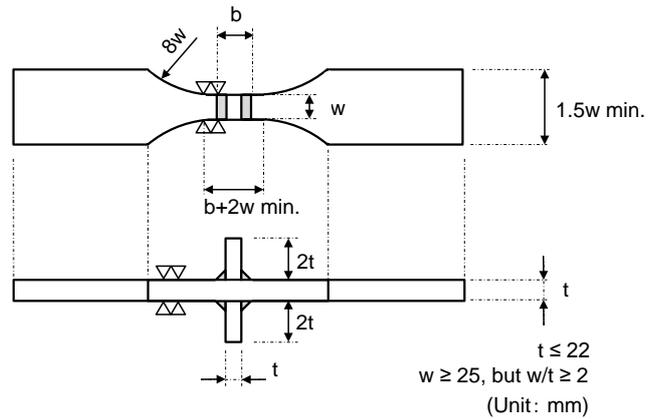
The welding procedure for the fabrication of test specimens should be as far as possible in accordance with the normal welding practice used at the shipyards for the type of steel in question.

Welding of test specimens should be carried out in the presence of the Surveyor, if deemed necessary by the Classification Society. In addition, any post-weld treatment improving fatigue properties of the welded joints shall not be carried out. In the case where any item improving the said fatigue properties intentionally (e.g. weld bead with too large flank angle) is found by the Surveyor, re-welding of test specimens may be required.

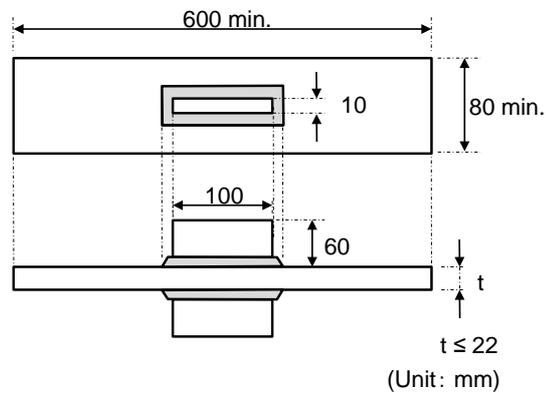
Visual Testing, Magnetic particle Testing or Penetrant Testing may be required after welding at the discretion of the Classification Society.

In order to reduce the bending stress due to angular deformation of the test specimen, the amount of angular deformation of the test piece should preferably be controlled at 5/1000 or less (see Fig. 3). In the case where the angular deformation of the test specimen is to be corrected, the correction shall not be performed on the weld metal and its proximity.

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(a) Transverse non-load-carrying fillet welded joint



(b) Longitudinal fillet welded gusset

Fig. 2 Dimensions of fatigue test specimens

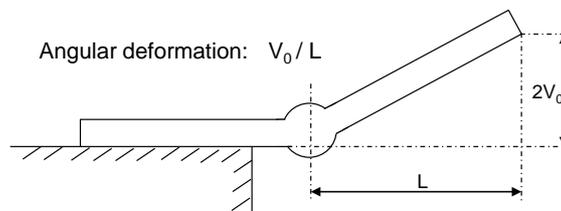


Fig. 3 Angular deformation of test specimen

2.3.3 Number of Fatigue Test Specimens

For each batch presented, unless otherwise agreed by the Classification Society, one (1) test sample is to be taken from the test piece unless the weight of the products is greater than 100 tons or fraction thereof.

One (1) set of two (2) fatigue test specimens is to be prepared from one (1) test sample. Each of two (2) stress ranges shown in Table 2 is to be tested, respectively.

The piece selected for the preparation of the test sample is to be the thickest in each batch.

The number of fatigue test specimens in the product inspection tests may be increased at the discretion of the Classification Society.

2.3.4 Fatigue Tests in Production Tests

The fatigue tests are to be carried out before dispatch.

Test conditions shown in Table 2 are to be satisfied at least. Test conditions other than Table 2 are to comply with a recognized national or international standard.

Table 2 Fatigue test conditions

Kind of joints	Stress ratio $R (= \sigma_{\min} / \sigma_{\max})$	Max. stress σ_{\max}	Stress range $\Delta\sigma$ (N/mm ²)	
			70 ^{*2}	150 ^{*2}
Transverse non-load-carrying fillet welded joint	–	ReH ^{*1}	70 ^{*2}	150 ^{*2}
Longitudinal fillet welded gusset	0.1	–		

Notes:

*1 ReH : specified minimum yield strength of the test steel

*2 Required min. Nf for these stress ranges are shown in Notes of Table 1.

*3 The loading frequency without heat generation should be selected.

Alternative tests other than fatigue tests in consideration of the relevant improvement mechanism of the fatigue properties may be accepted subject to the approval by the Classification Society based on the satisfactory technical background concerned.

It is recommended that the fatigue tests are continued until the failure of the test specimens.

All the test specimens are to be selected and stamped by the Surveyor and tested in his presence, unless otherwise agreed.

2.3.5 Kind of Joints for Fatigue Tests

The kind of welded joints for fatigue tests in the production tests (see Table 2) are to be agreed between the steel manufacturer and the purchaser, unless otherwise specified by the Classification Society.

2.3.6 Retest Procedures

Where the fatigue test specimens for two (2) stress ranges fail to satisfy the specified fatigue properties together, the batch is to be rejected.

Where the Nf (number of cycles to failure) of the fatigue test is less than 70% of the specified fatigue properties, re-testing is not allowed and the batch is to be rejected.

Where one of the fatigue test specimens fails to satisfy the specified fatigue properties, two (2) additional test specimens for the stress range concerned may be taken from the same batch of steels for re-testing. In the re-testing, if both of these additional specimens are tested with satisfactory results, the batch may be accepted.

2.4 Branding

2.4.1 The suffix “-FR” is to be affixed to the corresponding grade of hull structural steels defined in UR W11 (e.g. A36-FR).

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2.5 Documentation

2.5.1 In addition to the particulars specified in UR W11, the relevant test certificates or shipping statements are to contain the acceptance and the kind of welded joints of fatigue tests in the production tests.

Appendix

Additional Requirements for Manufacturing Approval of Hull Steels with Improved Fatigue Properties

A1. Scope of Application

A1.1 General

A1.1.1 This document gives the additional requirements for manufacturing approval tests and relevant documents for hull steels with improved fatigue properties (hereinafter called "fatigue resistant steels").

A1.1.2 In addition to the requirements in this document, Appendix A to UR W11 is to be followed.

A2. Application for Approval

A2.1 Additional Documents related to Fatigue Properties

A2.1.1 The steel manufacturer is to submit to the Classification Society a request for approval, which is to include the following:

- (1) Documents listed in 2.1 of Appendix A2 to UR W11
- (2) Fatigue properties improvement mechanism of the steels for approval;
- (3) The grades (including the suffix) to be approved;
- (4) In-house fatigue test results, if available.

A3. Approval Tests related to Fatigue Properties

A3.1 Extent of the Approval Tests

A3.1.1 Requirements for the extent of the approval tests specified in 3.1 of Appendix A2 to UR W11 are to be followed.

A3.2 Approval Test Program

A3.2.1 The test program submitted by the steel manufacturer is to be reviewed by the Classification Society, and if found satisfactory, it will be approved and returned to the steel manufacturer for acceptance prior to tests being carried out. Items that need to be witnessed by the Surveyor will be identified.

A3.3 Approval Survey

A3.3.1 The approval tests are to be witnessed by the Surveyor at the steel manufacturer's plant. If the testing facilities are not available at the works, the tests are to be carried out at the laboratories accepted by the Classification Society.

A3.3.2 The factory inspection may be required by the Surveyor during the visit for the approval as appropriate.

A3.3.3 All the test specimens are to be selected and stamped by the Surveyor.

A3.4 Selection of Test Piece

A3.4.1 For each grade of steels and for each manufacturing process (e.g. steel making, casting, rolling and condition of supply), one (1) test piece with the maximum thickness (dimension) to be approved is in general to be selected for each kind of product.

A3.4.2 In addition, for initial approval, the Classification Society may require selection of one (1) test piece of average thickness.

A3.4.3 The selection of the casts for the test product is to be based on the typical chemical composition, with particular regard to the specified C_{eq} or P_{cm} values and grain refining micro-alloying additions.

A3.4.4 The corresponding grade of non-fatigue resistant hull structural steels complying with UR W11 with the same thickness of fatigue resistant steels tested is to be prepared as a reference material for comparison.

A3.5 Position of Test Samples

A3.5.1 The test samples are to be taken, unless otherwise agreed, from the test piece corresponding to the top of the ingot, or, in the case of continuous casting, a random sample.

A3.5.2 The position of the samples to be taken in the length of the piece is to be "top".

A3.5.3 The direction of the test specimens with respect to the final direction of rolling of the material is to be "longitudinal".

A3.5.4 The position of the samples in the width of the product is to be in accordance with UR W11.

A3.6 Fatigue Tests

A3.6.1 The requirements related to the fatigue test specimens specified in 2.3.2 are to be satisfied.

A3.6.2 The requirements related to fatigue test procedures specified in 2.3.4 are to be satisfied and additional three (3) stress ranges are to be tested as stated in Table A1.

Table A1 Stress ranges to be tested

Kind of joints	Stress ranges to be tested $\Delta\sigma$ (N/mm ²)	Examples of additional stress range $\Delta\sigma$ (N/mm ²)
Transverse non-load-carrying fillet welded joint	70 and 150	100, 130, and 180
Longitudinal fillet welded gusset		

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In the case where in-house fatigue test results mentioned in A2.1.1 (3) are regarded adequate by the Classification Society, the number of additional stress ranges may be reduced to one (1).

A3.6.3 For each stress range, five (5) test specimens are to be tested. In the case where in-house fatigue test results mentioned in A2.1.1 (3) are regarded adequate by the Classification Society, the number of test specimens for each stress range may be reduced to three (3).

A3.6.4 The number of test specimens and stress ranges for the tests of non-fatigue resistant hull structural steels mentioned in A3.4.4 above are as follows:

Number of test specimens: Three (3) for each stress range
Stress ranges to be tested: To be in accordance with A3.6.2

A3.6.5 The number of fatigue test specimens may be increased at the discretion of the Classification Society.

A3.6.6 The fatigue tests should be continued until the failure of the test specimens.

A3.7 Additional Tests related to Improvement Mechanism of Fatigue Properties

A3.7.1 Additional tests in order to confirm the improvement mechanism of the fatigue properties may be required when deemed necessary by the Classification Society.

A4. Results of Fatigue Tests**A4.1 Fatigue test report**

A4.1.1 After completion of the manufacturing approval test, the steel manufacturer is to prepare fatigue test report to be included in the dossier required in UR W11.

A4.2 Judgment of acceptance

A4.2.1 The Society will give approval for fatigue resistant steels where all the fatigue test results are considered by the Classification Society to have the required fatigue properties (S-N curve in-air environment) mentioned in 2.2 based on the data submitted in accordance with the provisions of this Appendix.

A4.2.2 Additional tests for fatigue resistant steels and/or non-fatigue resistant hull structural steels may be required by the Classification Society in consideration of the fatigue test results of non-fatigue resistant hull structural steels mentioned in A3.4.4.

A4.2.3 All the results, which are in any case to comply with the requirements of this document, are evaluated for the approval; depending on the results, particular limitations or testing conditions, as deemed appropriate, may be specified in the approval document.

A5. Renewal of Approval**A5.1 Data to be submitted**

A5.1.1 The fatigue test results in relevant testing and inspection during the period between previous manufacturing approval (initial or renewal) and the validity date are to be submitted.

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A5.1.2 The above test results are to comply the following at least:

- (1) The fractured test specimens and non-fractured test specimens are to be classified;
- (2) The mean S-N curve by least square estimation and the standard deviation of log Nf (number of cycles to failure) are to be analysed statistically only for the results of the fractured test specimens.

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