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Guidelines for Friction Stir Welding

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APPLICATION OF
"Guidelines for Friction Stir Welding"

1. This guideline provides criteria applied to approval and inspection of friction stir welding used for joining aluminum alloys on ships.

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CHAPTER 1 GENERAL

Section 1 General

101. Application

1. This Guideline is applicable to the approval and inspection of friction stir welding used for joining aluminum alloys for ship structure.

2. Friction stir welding is mainly applied to welding of aluminum alloys, but approval and inspection of friction stir welding for joining materials other than aluminum alloys can be carried out with the approval of the Society.

3. The requirements other than this Guideline are to be in accordance with **Pt 2** of the Rules.

4. The requirements of inspection and test in accordance with national or international standards may also be applied to the approval at the discretion of the Society provided standard is considered equivalent to this Guideline from technical perspective covering examination, testing and inspection. And alternative standards or codes are to be applied in full, cross-mixing requirements of standards and codes is not permitted.

102. General

1. A shipyard/manufacturer applying friction stir welding is to be satisfied the following conditions.

(1) It should be ensured that there are no problems in welding quality and safety by the appropriate equipment and control system necessary for the friction stir welding process.

(2) A shipyard/manufacturer can use the friction stir welding for shipbuilding after the completion of approval for welding operator and welding procedure qualification test.

2. The shipyard/manufacturer shall conduct the production weld test for the approved WPS in accordance with **Chapter 4** of this guideline while applying friction stir welding to the actual construction.

3. If a serious defect or damage occurs during and after the welding process, appropriate follow-up measures should be taken and the results of the report of investigation should be submitted to the surveyor.

4. Welding procedures and the specification approved by the Society are valid on the sites controlled by the approved friction stir welding equipment and quality system.

103. Principle of friction stir welding

1. To produce high quality butt joints, a non-consumable rotary tool is used that moves along the joining line, which typically consists of a shoulder and a probe, as shown in **Figure 1**.

2. The tools for friction stir welding should be made of wear-resistant materials with excellent static and dynamic properties even at elevated temperatures. Due to the stirring effect of such a tool, the weld cross section must be made of a nugget having a ring shape to eliminate defects such as pores.

3. The shape of the joint is asymmetrical, and it is classified into a nugget, thermo-mechanical and heat-affected zone according to the microstructure.

4. Control variables in friction stir welding include tool rotation speed, axial load, welding speed, and tool shape.

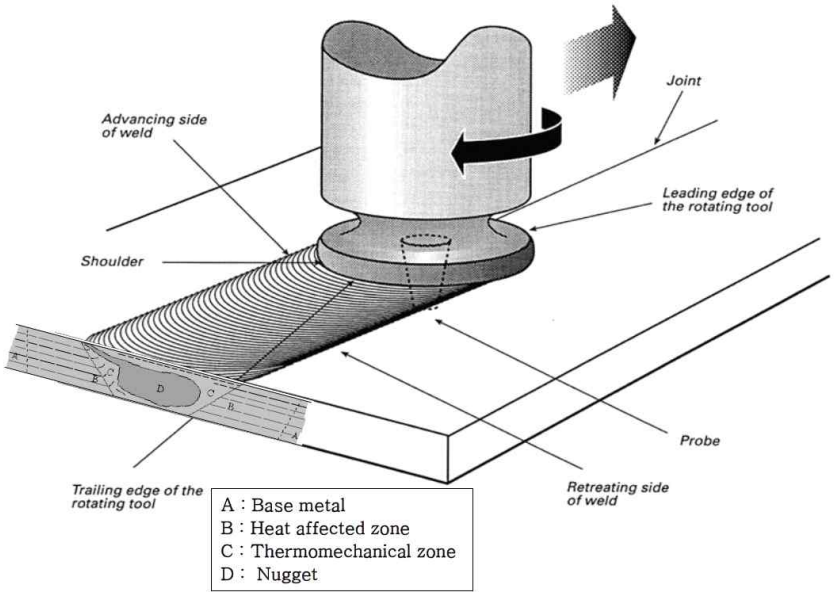


Fig. 1 Tool configuration and weld cross section used in friction stir welding

CHAPTER 2 WELDING OPERATOR

Section 1 General

101. Application

1. The requirements of this Chapter apply to the approval of welding operator and tests, etc.
2. The requirements other than this Chapter are to be in accordance with **Pt 2**, **Ch 2**, **Sec 5** of the Rules.

102. General

1. The shipyard/manufacturer is to be controlled that an welding operator is engaged in welding with the approved equipment.
2. The welding operator for friction stir welding is to be skilled in the operation of related equipment and perform welding in accordance with the approved welding procedure specifications. In addition, after judging the presence or absence of welding defects by welding operator, repair welding and measures are to be taken according to the approved welding procedure specification.
3. Notwithstanding the requirements in this Chapter, if the Surveyor deems that additional tests are necessary, additional tests for welding operator may be requested.

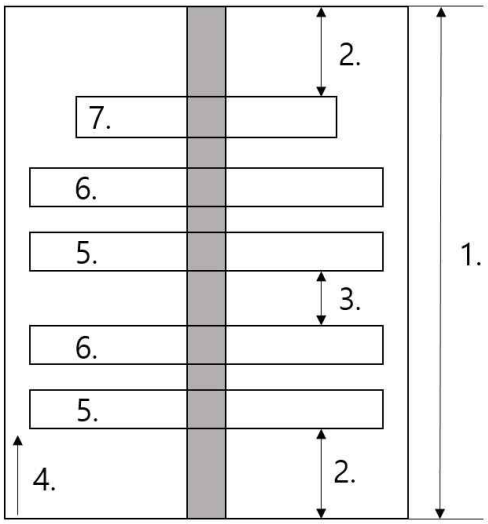
Section 2 Welding Operator Qualification Test

201. General

1. The shipyard/manufacturer is to be controlled that an welding operator is engaged in welding with the approved equipment.
2. The Surveyor is to be present in the welding of test assemblies and the testing of specimens.

202. Test assemblies

1. The directions for left and right and up and down are to be marked on the test assemblies.
2. The test assemblies are to be prepared in accordance with **Fig 2**.



(Notes)
1: minimum 500 mm
2: minimum 50 mm or three times the weld penetration whichever is greater
3: minimum 50 mm
4: weld direction
5: area for root bend test specimen
6: area for face bend test specimen
7: area for test specimen for macroscopic examination

Fig 2 Test assemblies for welding operator qualification test

203. Qualification tests

1. Test and examination

The kinds of test and acceptance criteria are to be accordance with **Table 1**.

Table 1 Kinds of test and acceptance criteria

Kinds of test	Test method and acceptance criteria(1)
Visual examination	- Visual examination for welding positions of whole length - It is evaluated according to quality level B of **ISO 25239-5**, ANNEX A.
Bend test	- Bend test with two root bend specimens and two face bend specimens - The test method and acceptance criteria are in accordance with **Pt 2**, **Ch 2**, **404.** of the Rules.
Macroscopic examination	- The test method is in accordance with **Pt 2**, **Ch 2**, **404.** of the Rules. - It is evaluated according to quality level B of **ISO 25239-5**, ANNEX A.
NOTES: (1) The test specimens are taken from test assembly as shown in **Fig 2**.	

2. Retest

The retest is in accordance with **Pt 2**, **Ch 2**, **503. 4** of the Rules.

204. Range of qualification

1. Types of welded joint

A successful test weld made in any weld joint geometry qualifies an operator for all weld joint geometries.

2. Base materials

(1) The range of qualification for base materials is in accordance with **Pt 2**, **Ch 2**, **502. 5** of the Rules.
(2) The range of qualification for thickness and outer diameter of base materials is in accordance with **Pt 2**, **Ch 2**, **502. 6** of the Rules. However, the welding operators qualified for plates are permitted the welding for pipe regardless of the thickness and diameter of the pipe.

3. Welding equipment

The following changes require a new qualification.
(1) A change from welding with a joint sensor to welding without, although welding without a joint sensor also qualifies an operator to weld with a joint sensor (i.e. location, height mismatch, ···)
(2) A change from one type of welding machine to another type of welding machine that requires additional training to operate
(3) A test made with any type of machine qualifies only that type of machine, although the addition or removal of jigs and fixtures, feeding units and other ancillary equipment does not change the type of machine
(4) Addition, removal or change of control system

3. Positions

The range of qualification for position is in accordance with **Pt 2**, **Ch 2**, **502. 7** of the Rules.

205. Qualification validity

The qualification validity for welding operator is in accordance with **Pt 2**, **Ch 2**, **504.** of the Rules.

CHAPTER 3 WELDING PROCEDURE QUALIFICATION TESTS

Section 1 General

101. General

1. Application

(1) The requirements for this Chapter apply to welding procedure qualification tests for friction stir welding.

(2) The requirements other than this Chapter are to be in accordance with **Pt 2**, **Ch 2**, **Sec 4** of the Rules.

2. Data to be submitted

(1) The shipyard/manufacturer who has the first approval of the welding procedure specification for friction stir welding is to be submitted the technical file with pWPS. The technical file is to be included the detailed specifications of the friction stir welding equipment and the test results to understand the mechanical properties such as the tensile test, etc. of the weld.

(2) If the items listed in the submitted technical file are changed or the Surveyor specifically requests, the changed description is to be resubmitted.

102. Welding procedure specification

1. The requirements for welding procedure specification are to be in accordance with **Pt 2**, **Ch 2**, **Sec 4**, **402.** of the Rules.

2. In addition to the requirements of **Pt 2**, **Ch 2**, **Sec 4**, **402.** of the Rules, the following welding parameters are to be described in the welding procedure specification.

(1) Equipment identification
  (A) Model
  (B) Serial number
  (C) Equipment fabricator

(2) Tool identification
  (A) Material
  (B) Drawing or drawing number

(3) Clamping arrangement
  (A) Method and type of jigging, fixtures, roller, and backing(dimensions and material)
  (B) Tack welding process and conditions, when required
  (C) The pWPS shall indicate any required tack welding or prohibited tack welding
  (D) Assembly requirements(i.e. welding gap, misalignment)

(4) Joint preparation and cleaning methods

(5) Welding details
  (A) Method(basic, stationary shoulder, bobbin tool, etc.)
  (B) Tool motion(e.g. rotation in either the clockwise or anticlockwise direction, rotation speed including downward and upward motion)
  (C) Tool position(e.g. heel plunge depth) or axial force, as applicable
  (D) Tool cooling(internal, external, cooling medium), if applicable
  (E) Tilt angle
  (F) Side tilt angle, lateral offset
  (G) Dwell time at start of weld
  (H) Dwell time at end of weld
  (I) Weld Overlap Area(WOA) for a butt joint in pipe

(6) Welding speed
  (A) Welding speed, including details of any changes during welding
  (B) Ramp-up/ramp-down or upslope/downslope speeds when applied

(7) Thermal management
  (A) Details of any pre-weld heat treatment, if applicable
  (B) Details of the preheating temperature, preheat maintenance temperature and/or interpass temperature for the base materials or the friction stir welding tool, if applicable
  (C) Details of any postweld heat treatment (e.g. solution heat treatment, ageing, stress relieving),

if applicable

(D) details of any methods for managing the cooling rates (e.g. gas flows, liquid environments) applied prior, during or after welding, if applicable

(8) Postweld (mechanical) processing: methods to correct distortion and straighten parts, removal of toe flash or any other postweld processing of the weldment.

Section 2 Welding Procedure Qualification Tests

201. General

1. Where procedure qualification test is required, the test assembly is to be welded in the same or similar environment and the qualification tests are to be carried out under the welding conditions given in the pWPS.

2. Welding of the test assemblies and testing of test specimens are to be witnessed by the Surveyor.

3. If tack welds and/or start and stop points are a condition of the weld process they are to be fused into the joint and are to be included in the test assemblies.

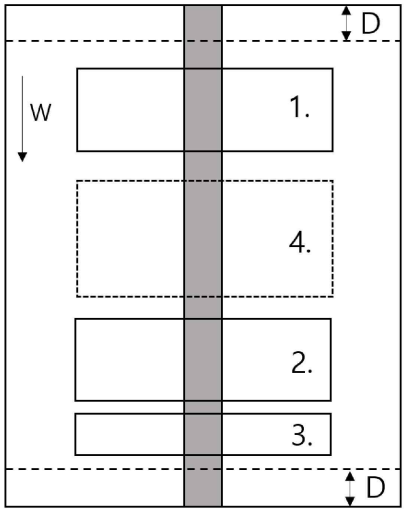
4. Tests or test conditions other than those specified in this Section for the welding procedure qualification may be required, where deemed necessary by the Society.

202. Tests for butt welded joints

1. Test assemblies

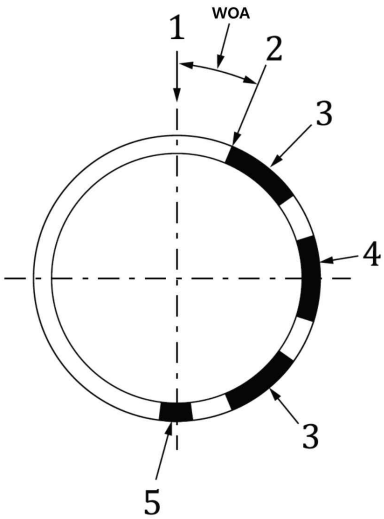
(1) Test assemblies are to be prepared with the same or equivalent material used in the actual work.

(2) The types of test assembly are to be as indicated in **Fig 3** and **Fig 4**. The dimensions of the test assembly is to be sufficient to allow all required tests to be performed. And the length of the test assembly should allow a welding length of at least 500 mm.



(Notes)
1: area for one transverse tensile test specimen and each one root/face bend test specimens
2: area for one transverse tensile test specimen and each one root/face bend test specimens
3: area for one test specimen for macroscopic examination
4: area for additional test specimens, if required
D: Discard
W: Direction of welding

Fig 3 Test assemblies for butt welded joint



(Notes)
1: start of weld
2: end of weld
3: area for one transverse tensile test specimen and each one root/face bend test specimens
4: area for additional test specimens, if required
5: area for one test specimen for macroscopic examination
WOA(Weld Overlap Area): one transverse tensile test specimen, if possible

Fig 4 Test assemblies for butt welded joint of pipe

2. Kinds of test

The kinds of test and acceptance criteria are to be given in **Table 2**.

Table 2 Kinds of test and acceptance criteria

Kinds of test	Test method and acceptance criteria(1)
Visual examination	- Prior to the cutting of test specimen, visual examination for welding positions of whole length - It is evaluated according to quality level B of **ISO 25239-5**, ANNEX A.
Tensile test	- Tensile test with two transverse tensile test specimens - The test method and acceptance criteria are in accordance with **Pt 2**, **Ch 2**, **404.** of the Rules.
Bend test	- Bend test with two root bend specimens and two face bend specimens - The test method and acceptance criteria are in accordance with **Pt 2**, **Ch 2**, **404.** of the Rules.
Macroscopic examination	- The test method is in accordance with **Pt 2**, **Ch 2**, **404.** of the Rules. - It is evaluated according to quality level B of **ISO 25239-5**, ANNEX A.
Non-destructive test	- Prior to the cutting of test specimen, NDT for welding positions of whole length - Internal inspections by radiographic examination or ultrasonic examination and surface inspections by liquid penetrant examination are to be carried out. - It is evaluated according to quality level B of **ISO 25239-5**, ANNEX A.
NOTES: (1) The test specimens are taken from test assembly as shown in **Fig 3** and **Fig 4**.	

203. Retests and Procedure qualification records(PQR)

The retests and procedure qualification records are in accordance with **Pt 2**, **Ch 2**, **Sec 4**, **406.** of the Rules.

204. Validity of qualified welding procedure specification

1. A qualification test carried out by a shipyard/fabricator is valid for welding on the same type of welding machine installed in workshops or sites under that shipyard/fabricator's technical and quality control.

2. For the validity other than the above **1.**, it is to be in accordance with **Pt 2**, **Ch 2**, **Sec 4**, **407.** of the Rules.

CHAPTER 4 PRODUCTION WELD TESTS

Section 1 General

101. General

1. Application

(1) The requirements for this Chapter apply to the tests to confirm the integrity and mechanical properties of the welds while performing friction stir welding on the shipbuilding.
(2) The requirements other than this Chapter are to be in accordance with **Pt 2**, **Ch 2**, **103.** of the Guidance.

Section 2 Test and Examination

201. Non-destructive test

The non-destructive test is carried out in the following three areas, and the external and internal quality of the friction stir welding joint of the ship should be checked.

(1) Start and end part of weld(including repair welds of end part)
(2) Areas deemed necessary by the surveyor
(3) Every 200 m of welding length of butt joints for friction stir welding

202. Kinds of test

The kinds of test and acceptance criteria are to be given in **Table 3**. For each vessel, it is carried out once for the same type of welding equipment.

Table 3 Kinds of test and acceptance criteria

Kinds of test	Test method and acceptance criteria(1)
Visual examination	- Prior to the cutting of test specimen, visual examination for welding positions of whole length - It is evaluated according to quality level B of **ISO 25239-5**, ANNEX A.
Tensile test	- Tensile test with two transverse tensile test specimens - The test method and acceptance criteria are in accordance with **Pt 2**, **Ch 2**, **404.** of the Rules.
Bend test	- Bend test with two root bend specimens and two face bend specimens - The test method and acceptance criteria are in accordance with **Pt 2**, **Ch 2**, **404.** of the Rules.
Macroscopic examination	- The test method is in accordance with **Pt 2**, **Ch 2**, **404.** of the Rules. - It is evaluated according to quality level B of **ISO 25239-5**, ANNEX A.
NOTES: (1) The dimensions of the test assembly is to be sufficient to allow all required tests to be performed.	

GUIDELINES FOR FRICTION STIR WELDING

Published by
KR
36, Myeongji ocean city 9-ro, Gangseo-gu,
BUSAN, KOREA
TEL : +82 70 8799 7114
FAX : +82 70 8799 8999
Website : http://www.krs.co.kr