



2023

Guidelines for Laser-arc Hybrid Welding

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KR

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APPLICATION OF
"Guidelines for Laser–arc Hybrid Welding"

1. This guideline provides criteria applied to approval and inspection of Laser–arc hybrid welding used for joining steels 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 laser-arc hybrid welding used for joining steels for ship structure.
2. Laser-arc hybrid welding is mainly applied to welding of steel, but approval and inspection of laser-arc hybrid welding for joining materials other than steel 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 laser-arc hybrid welding shall be satisfied the following conditions.
 - (1) It shall be ensured that there are no problems in welding quality and safety by the appropriate equipment and control system necessary for laser-arc hybrid welding process.
 - (2) A shipyard/manufacturer can use the laser-arc hybrid 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 laser-arc hybrid welding to the actual construction.
3. If a serious defect or damage occurs during and after the welding process, appropriate follow-up measures shall 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 laser-arc hybrid welding equipment and quality system.

103. Principle of laser-arc hybrid welding

1. The combination of laser and arc welding techniques is called laser-arc hybrid welding, a descriptive term that includes the laser type (i.e. CO₂, Nd: YAG) and the arc welding process (MIG/MAG, TIG). Laser-arc hybrid welding is a process in which the laser beam and the arc are combined in one process zone and form one joint melt pool . (Refer to Fig 1)
2. Laser-arc hybrid welding gives smaller heat input, and hence smaller welding zones, than conventional welding processes. Therefore, strict control of all geometrical tolerances for materials to be welded is necessary.
3. Similarly, strict requirements shall be set to the positioning of the welding equipment. Experience has shown that a likely type of weld defect is that the welding arc fails to hit the groove, so that the groove remains (wholly or partly) as a large defect. For this reason, only full penetration welds, where correct positioning of the weld can be verified by visual inspection of the root side, is acceptable.
4. To correctly position the weld, the welding device is equipped with a a “seam tracker”, to know exactly the position of the groove. Since these devices are sensitive to changes in surface prop-

erties, appropriate management is required. (i.e. light reflection of surface).

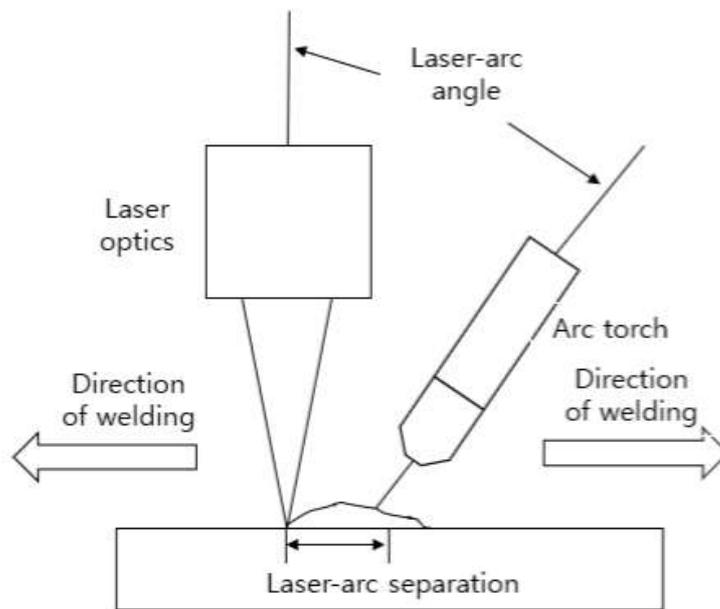


Fig. 1 Schematic diagram of the laser-arc hybrid welding process

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 shall be controlled that an welding operator is engaged in welding with the approved equipment.
2. The welding operator for laser-arc hybrid 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. Welding operators responsible for setting up and/or adjustment of fully mechanized and automatic equipment, such as the laser-arc hybrid welding with auto-carriage, etc., must be qualified whether they operate the equipment or not. However a welding operator, who solely operates the equipment without responsibility for setting up and/or adjustment, does not need qualification provided that he has experience of the specific welding work concerned and the production welds made by the operators are of the required quality.
4. Not with standing the requirements in this Chapter, if the Surveyor deems that additional tests are necessary, additional tests for welding operator may be requested.

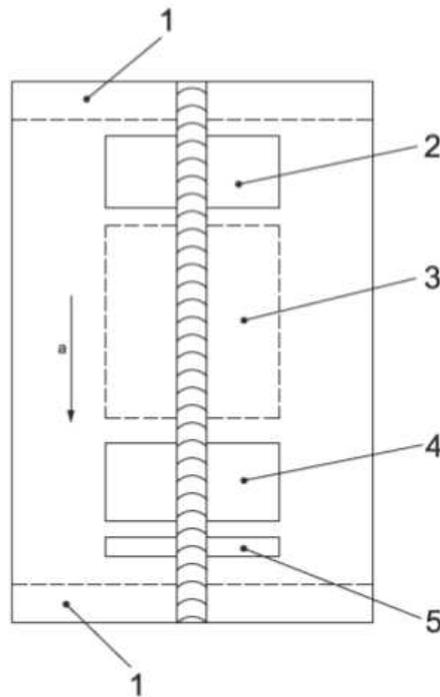
Section 2 Welding Operator Qualification Test

201. General

1. The dimensions and types of welded joint are to be in accordance with WPS or pWPS. However, it is possible to conduct a welding operator qualification test and a welding procedure qualification test at the same time.
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) Total length : Min. 1000mm

1: discard minimum 50 mm

2: area for each one tensile test specimen and bend test specimens

3: minimum 50 mm

4: area for each one tensile test specimen and bend test specimens

5: area for test specimen for macroscopic examination

a: direction of welding

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	<ul style="list-style-type: none"> - Visual examination for welding positions of whole length - The imperfections detected by testing are to be assessed in accordance with ISO 5817, class B, except for imperfection type such as excessive convexity and excessive throat thickness for which level C applies
Bend test	<ul style="list-style-type: none"> - Bend test with two root bend specimens and two face bend specimens. Where the thickness of the test assembly exceeds 12 mm, two side bend test specimens may be used. - The test method and acceptance criteria are in accordance with Pt 2, Ch2, 404. of the Rules.

Macroscopic examination	<ul style="list-style-type: none"> - The test method is in accordance with Pt 2, Ch 2, 404. of the Rules. - The imperfections detected by testing are to be assessed in accordance with ISO 5817, class B, except for imperfection type such as excessive convexity and excessive throat thickness for which level C applies
<p>(비 고)</p> <p>(1) The test specimens are taken from test assembly as shown in Fig 2.</p>	

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 of base materials is in accordance with **Pt 2, Ch 2, 502. 6** of the Rules.

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

4. 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 SPECIFICATION AND WELDING PROCEDURE QUALIFICATION TESTS

Section 1 General

101. General

1. Application

- (1) The requirements for this Chapter apply to welding procedure specification and welding procedure qualification tests for laser-arc hybrid welding.
- (2) The requirements other than this Chapter are to be in accordance with **ISO 15609-6, ISO 15614-14, Pt 2, Ch 2, Sec 4 of the Rules.**

2. Submitted documents

- (1) A welding procedure specification (WPS) is to be prepared by the shipyard or manufacturer which intends to perform the welding procedure qualification test. This document is also referred to as a preliminary welding procedure specification (pWPS). The shipyard or manufacturer is to submit to the Society a pWPS for review prior to the tests.
- (2) If the items listed in the submitted WPS 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 **ISO 15609-6** of the Rules.
2. In addition to the requirements of **ISO 15609-6** 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) The following items according to the thickness of the base metal (classification of representative thicknesses including the approved desired maximum thickness)
 - (A) Groove shape and dimensions (standard tolerances for groove angle, root gap, misalignment, etc.)
 - (B) Build-up procedure
 - (C) Laser beam welding conditions (type of laser, output, beam diameter, laser focusing position, etc.)
 - (D) Arc welding conditions (polarity, current, voltage, heat input, etc.)
 - (E) Arrangement of laser and arc torches (torch sequence, laser/arc torch advancing/receding angle, laser/arc torch tilt angle, distance between torches, etc.)
 - (F) Welding speed
 - (G) Details of any pre-weld heat treatment, if applicable
 - (H) Details of any postweld heat treatment, if applicable (e.g. solution heat treatment, ageing, stress relieving)
 - (I) Details of any methods for managing the cooling rates (e.g. gas flows, liquid environments) applied prior, during or after welding, if applicable
 - (3) Postweld (mechanical) processing: methods to correct distortion and straighten parts, removal of toe flash or any other postweld processing of the weld.
3. In case that the test pieces welded according to the pWPS show unacceptable results the pWPS is to be adjusted by the shipyard or manufacturer. The new pWPS is to be prepared and the test pieces welded in accordance with the new pWPS.
4. The WPS is to be used as a basis for the production welds, and upon satisfactory completion of the tests based on the pWPS, the Society may approve it as a WPS. In case that a WPS is ap-

proved by the Society the approval range is to be in compliance with the requirements in 205.

Section 2 Welding Procedure Qualification Tests

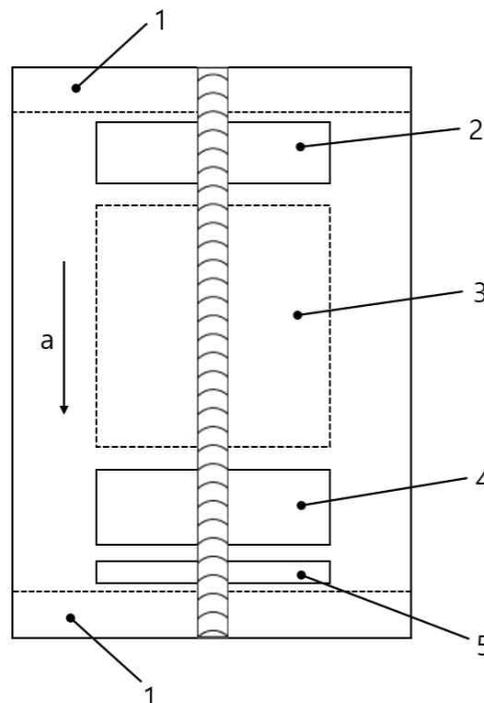
201. General

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.
5. In the case of qualification tests for test assemblies and specimens not presented in this section, test assemblies and specimens should be prepared in accordance with the conditions presented in ISO 15614-14

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**. 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 1000 mm and width of at least 400 mm.



(Note) 1: Discard(50mm)

- 2: area for each one tensile test specimen, bend test specimens(face/root or side), each one test specimen for macroscopic examination and hardness test
- 3: area for charpy impact test, additional test specimens if required

- 4: area for each one tensile test specimen, bend test specimens(face/root or side)
 5. area for each one test specimen for macroscopic examination and hardness test
 a: Direction of welding

Fig. 3 Test assemblies for butt welded joint

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	<ul style="list-style-type: none"> – Visual examination for welding positions of whole length – The imperfections detected by testing are to be assessed in accordance with (KS B) ISO 5817, class B, except for imperfection type such as excessive convexity and excessive throat thickness for which level C applies
Tensile test	<ul style="list-style-type: none"> – 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	<ul style="list-style-type: none"> – Bend test with two root bend specimens and two face bend specimens. Where the thickness of the test assembly exceeds 12 mm, two side bend test specimens may be used. – The test method and acceptance criteria are in accordance with Pt 2, Ch2, 404, of the Rules.
Charpy V-notch impact test	<ul style="list-style-type: none"> – The test specimens is to be taken from the position in Fig 3. – The number of test specimens and the position of notch for the test specimen taken from test assemblies are as specified in Pt 2, Ch2, 404. – The test method and acceptance criteria are in accordance with Pt 2, Ch2, 404, of the Rules.
Macroscopic examination	<ul style="list-style-type: none"> – The test method is in accordance with Pt 2, Ch2, 404, of the Rules.
Non-destructive test	<ul style="list-style-type: none"> – 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. – The imperfections detected by testing are to be assessed in accordance with (KS B) ISO 5817, class B, except for imperfection type such as excessive convexity and excessive throat thickness for which level C applies
Hardness test	<ul style="list-style-type: none"> – The number of test specimens taken from test assemblies and the position of notch for the test specimen are as specified in Fig 3. – The test method and acceptance criteria are in accordance with Pt 2, Ch2, 404, of the Rules.

NOTES

(1) The test specimens are taken from test assembly as shown in **Fig. 3**

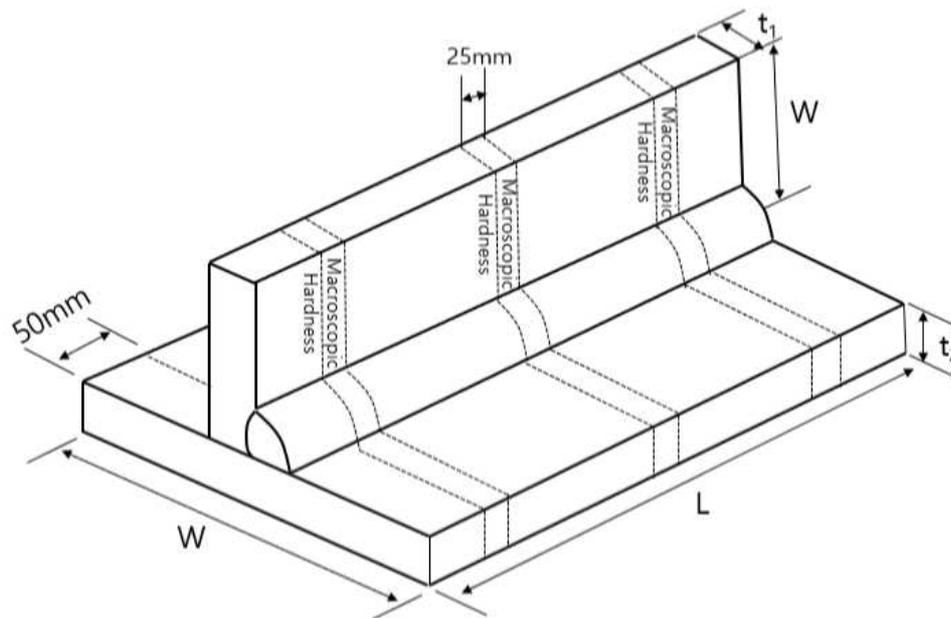
(2) The stop and restart points shall be included in the weld process, additional tests(macroscopic examination and hardness test) are required. A macroscopic examination specimen is to be

sampled from the end point of the location where weld stopped and hardness test specimen is to be sampled from location where restarted

203. Tests for T-joint with full penetration weld

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 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 1000 mm



(Notes)

1. The length of test specimen is as follows :

(1) Automatic welding: Width(W) : $3 \times t$. min. 150 mm

Length(L) : min. 1000 mm

2. Thickness of webs and flanges of the test assembly, t_1 및 t_2 are to be of ordinary thicknesses used in the actual work.
3. Tack weld may be applied to the test assembly.
4. The fillet length is to be of ordinary length used in the actual work

Fig 4 Test assembly for T-joint with full penetration (unit : mm)

2. Kinds of test

The kinds of test and acceptance criteria are to be given in **Table 3**.

Table 3 Kinds of test and acceptance criteria

Kinds of test	Test method and acceptance criteria ⁽¹⁾
---------------	----------------------------------------------------

Visual examination	<ul style="list-style-type: none"> – Visual examination for welding positions of whole length – The imperfections detected by testing are to be assessed in accordance with (KS B) ISO 5817, class B, except for imperfection type such as excessive convexity and excessive throat thickness for which level C applies
Macroscopic examination	<ul style="list-style-type: none"> – The test method and acceptance criteria are in accordance with Pt 2, Ch2, 405. of the Rules.
Non-destructive test	<ul style="list-style-type: none"> – 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. – The imperfections detected by testing are to be assessed in accordance with (KS B) ISO 5817, class B, except for imperfection type such as excessive convexity and excessive throat thickness for which level C applies
Hardness test	<ul style="list-style-type: none"> – The number of test specimens taken from test assemblies and the position of notch for the test specimen are as specified in Fig 4. – The test method and acceptance criteria are in accordance with Pt 2, Ch2, 405. of the Rules.
<p>NOTES</p> <p>(1) The test specimens are taken from test assembly as shown in Fig 4</p> <p>(2) The stop and restart points shall be included in the weld process, additional tests (macroscopic examination and hardness test) are required. A macroscopic examination specimen is to be sampled from the end point of the location where weld stopped and hardness test specimen is to be sampled from location where restarted</p>	

204. 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.

205. 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. The upper limit of nominal heat input qualified is 15 % greater than that used in welding the test piece. The lower limit of nominal heat input qualified is 15 % lower than that used in welding the test piece.

* Nominal heat input

$$Q_{nom} = \frac{(P + U \times I)}{\nu} 10^{-3}$$

Q_{nom} : Nominal heat input, kJ/mm

P : the laser power, kW

U : the arc voltage, measured as near as possible to the arc, V

I : the welding current, A

ν : the travel speed, mm/sec

3. The qualification of a WPS carried out on a plate or pipe test assembly of thickness t is valid for the thickness range given in **Table 4.** Combinations of different plate thicknesses shall be qualified

separately and the qualification applies only to that combination.

Table 4 Qualified thickness range for butt, T-joint welds

Thickness of test piece, t(mm)	Range of approval, T(mm)
$t < 5$	$T = t$
$t \geq 5$	$0.8t \leq T \leq 1.0t$

4. For the validity other than the above, 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 laser–arc hybrid 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

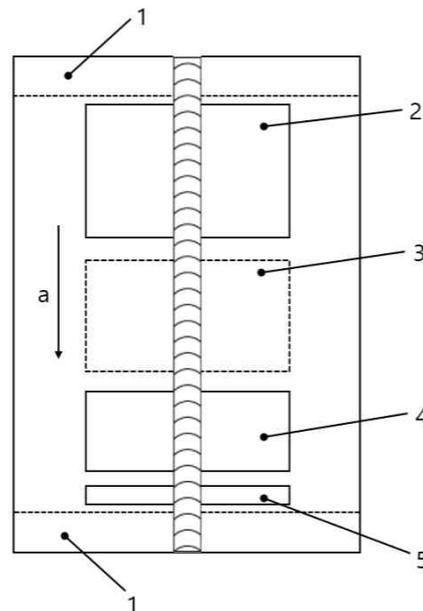
201. Non–destructive test

The non–destructive test is carried out in the following three areas, and the external and internal quality of the laser–arc hybrid 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 joints for laser–arc hybrid welding

202. Kinds of test

The kinds of test and acceptance criteria are to be given in Table 5 and Table 6. For each vessel, it is carried out once for the same type of welding equipment.

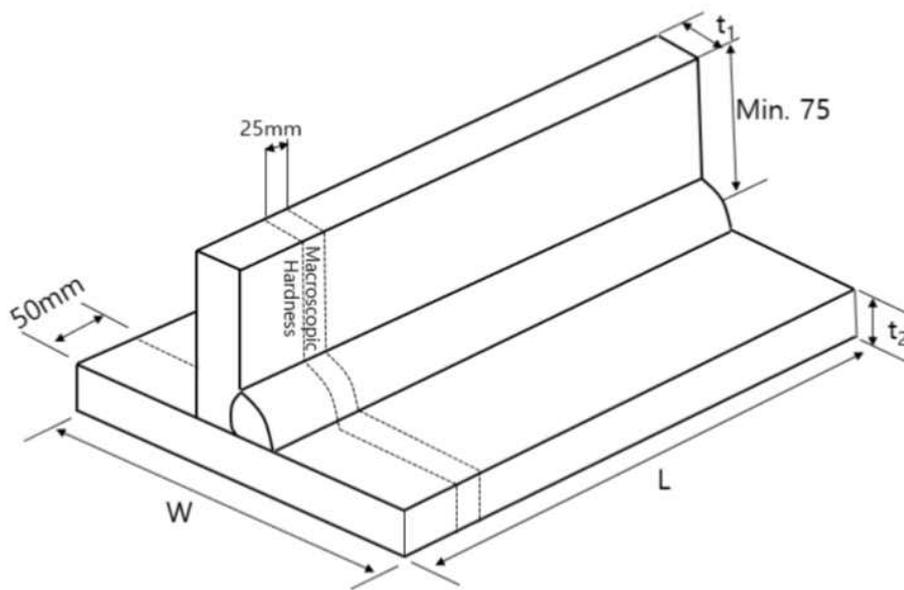


- (Note) 1: Discard(50mm)
 2: additional test specimens
 3: area for charpy impact test
 4: area for each one bend test specimens(face/root or side)
 5: area for each one tensile test specimen
 a: Direction of welding
 * Length : min. 500 mm, Width : min. 400 mm

Table 5 Kinds of test and acceptance criteria(Butt weld joint)

Kinds of test	Test method and acceptance criteria ⁽¹⁾
Visual examination	<ul style="list-style-type: none"> – Visual examination for welding positions of whole length – The imperfections detected by testing are to be assessed in accordance with (KS B) ISO 5817, class B, except for imperfection type such as excessive convexity and excessive throat thickness for which level C applies
Tensile test	<ul style="list-style-type: none"> – Tensile test with one transverse tensile test specimen – The test method and acceptance criteria are in accordance with Pt 2, Ch 2, 404. of the Rules.
Bend test	<ul style="list-style-type: none"> – Bend test with one root bend specimen and one face bend specimen. Where the thickness of the test assembly exceeds 12 mm, two side bend test specimens may be used. – The test method and acceptance criteria are in accordance with Pt 2, Ch2, 404. of the Rules.
Charphy V–notch impact test	<ul style="list-style-type: none"> – The number of test specimens taken from test assemblies are three(1 set) and the position of notch for the test specimen are as specified in Fig 5. – The position of notch for the test specimen taken from test assemblies are as specified in Pt 2, Ch2, 404. of the Rules.. – The test method and acceptance criteria are in accordance with Pt 2, Ch2, 404. of the Rules.
<p>NOTES</p> <p>(1) The dimensions of the test assembly is to be sufficient to allow all required tests to be performed.</p>	

Fig 5 Production weld test assemblies for butt welded joint



(Note)

1. The length of test specimen is as follows :

- (1) Automatic welding: Width(W) : min. 150 mm
 Length(L) : min. 150 mm

Fig 6 Production weld test assembly for T-joint with full penetration (unit : mm)

Table 6 Kinds of test and acceptance criteria(T-joint weld)

Kinds of test	Test method and acceptance criteria ⁽¹⁾
Visual examination	<ul style="list-style-type: none"> - Visual examination for welding positions of whole length - The imperfections detected by testing are to be assessed in accordance with (KS B) ISO 5817, class B, except for imperfection type such as excessive convexity and excessive throat thickness for which level C applies
Macroscopic examination	<ul style="list-style-type: none"> - The test method and acceptance criteria are in accordance with Pt 2, Ch2, 405. of the Rules.
Hardness test	<ul style="list-style-type: none"> - The number of test specimen taken from test assemblies is one and the position of notch for the test specimen are as specified in Fig. 6. - The test method and acceptance criteria are in accordance with Pt 2, Ch2, 405. of the Rules.
NOTES (1) The dimensions of the test assembly is to be sufficient to allow all required tests to be performed.	

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