INTERNATIONAL MARITIME ORGANIZATION

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4 ALBERT EMBANKMENT
LONDON SE1 7SR
Telephone: +44 (0)20 7735 7611 Fax: +44 (0)20 7587 3210

MSC.1/Circ.1622/Rev.1
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REVISED GUIDELINES FOR THE ACCEPTANCE OF ALTERNATIVE METALLIC MATERIALS FOR CRYOGENIC SERVICE IN SHIPS CARRYING LIQUEFIED GASES IN BULK AND SHIPS USING GASES OR OTHER LOW-FLASHPOINT FUELS

1 The Maritime Safety Committee, at its 102nd session (4 to 11 November 2020), acknowledging a potential need for alternative metallic materials to be used for the construction and safe operation of low-temperature fuel and cargo-carrying ships and the need for guidance in this respect, approved the *Guidelines for the acceptance of alternative metallic materials for cryogenic service in ships carrying liquefied gases in bulk and ships using gases or other low-flashpoint fuels* (MSC.1/Circ.1622), prepared by the Sub-Committee on Carriage of Cargoes and Containers (CCC), at its sixth session (9 to 13 September 2019).

2 The Maritime Safety Committee, at its 105th session (20 to 29 April 2022), approved amendments to the Guidelines (MSC.1/Circ.1648), prepared by the Sub-Committee on Carriage of Cargoes and Containers (CCC), at its seventh session (6 to 10 September 2021).

3 The Maritime Safety Committee, at its 108th session (15 to 24 May 2024), having qualified high manganese austenitic steel for ammonia service, and in order to revise additional compatibility test requirements for ammonia service, approved the Revised Guidelines for the acceptance of alternative metallic materials for cryogenic service in ships carrying liquefied gases in bulk and ships using gases or other low-flashpoint fuels, as set out in the annex, prepared by the Sub-Committee on Carriage of Cargoes and Containers (CCC), at its ninth session (20 to 29 September 2023).

4 The Revised Guidelines incorporate the amendments in MSC.1/Circ.1648 and provide detailed guidance on how to document alternative metallic materials for their suitability and compliance with the IGC and IGF Codes, and a framework for evaluation and approval of alternative metallic materials for cryogenic service.

5 Member States are invited to bring the annexed Revised Guidelines to the attention of all parties concerned.

6 This circular supersedes MSC.1/Circ.1622 and revokes MSC.1/Circ.1648.

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ANNEX

REVISED GUIDELINES FOR THE ACCEPTANCE OF ALTERNATIVE METALLIC MATERIALS FOR CRYOGENIC SERVICE IN SHIPS CARRYING LIQUEFIED GASES IN BULK AND SHIPS USING GASES OR OTHER LOW-FLASHPOINT FUELS

PART 1
GENERAL

1 Introduction

1.1 Ships carrying liquefied gases in bulk should comply with the requirements of the IGC Code adopted by resolution MSC.370(93), as amended. Ships using gases or other low-flashpoint fuels should comply with the requirements of the IGF Code, adopted by resolution MSC.391(95), as amended.

1.2 The requirements for metallic materials used in low temperature applications on board ships constructed in accordance with the IGC and IGF Codes are contained in tables 6.2, 6.3 and 6.4 of the IGC Code and tables 7.2, 7.3 and 7.4 of the IGF Code, respectively. The requirements are identical in both Codes and specify the minimum design temperatures for specific materials based upon chemical composition, mechanical properties and heat treatment. These approved materials have been incorporated in the Codes since their inception and have provided over 40 years of satisfactory service experience.

1.3 There is recent interest in adding new metallic materials to the list of those already covered by the Codes. *Interim guidelines on the application of high manganese austenitic steel for cryogenic service* were adopted and disseminated as MSC.1/Circ.1599. In the process of developing the Interim guidelines, significant experience in the evaluation of this alternative material was acquired. The recommendations contained in MSC.1/Circ.1599 are used as the basis for these Guidelines.

2 Application

2.1 These Guidelines apply to metallic materials not listed in tables 6.2, 6.3 and 6.4 of the IGC Code and tables 7.2, 7.3 and 7.4 of the IGF Code respectively. The testing requirements set out herein provide guidance for the acceptance of alternative metallic materials based upon the equivalency provisions contained in section 1.3 of the IGC Code or alternative design requirements contained in section 2.3 of the IGF Code. The Guidelines apply only to materials used for products listed in chapter 19 of the IGC Code or MSC circulars approved by the Organization, or fuels addressed by the IGF Code.

2.2 The Guidelines also apply to alternative metallic materials having a minimum design temperature between 0ºC and -165ºC or lower if authorized by the Administration in the range of minimum and maximum thicknesses tested during the approval process, up to a maximum thickness of 40 mm. Thicknesses in excess of 40 mm should be approved by the Administration or recognized organization acting on its behalf. In addition to approval for a minimum design temperature of -165ºC, alternative metallic materials may be approved for intermediate minimum design temperatures of -55ºC, -60ºC, -65ºC, -90ºC and -105ºC. Alternative metallic materials qualified at a lower temperature are suitable for use at the intermediate minimum design temperature.

2.3 The Guidelines only apply to alternative metallic materials formed or manufactured by rolling, extrusion, casting or forging.

2.4 Alternative metallic materials approved in accordance with the Guidelines may be used in the construction of cargo containment and piping system under chapter 4 of the IGC Code or similar parts of fuel tanks, under chapter 6 of the IGF Code or piping systems under section 5.12 of the IGC Code and section 7.4.1.2 of the IGF Code. They should be approved for specific cargoes or fuels listed in the IGC or IGF Codes based upon their design temperature and their compatibility with the cargo or fuel. This Guideline does not address material forming part of the hull structure.

3 Definitions

3.1 *Alternative metallic materials*: Homogeneous ferrous and non-ferrous alloys having uniform composition in any direction formed by hot rolling, cold rolling, extrusion, casting or forging, whose compositions or heat treatments are not listed in tables 6.2, 6.3 and 6.4 of the IGC Code and tables 7.2, 7.3 and 7.4 of the IGF Code, respectively.

3.2 *Established metallic materials*: Metallic materials listed in tables 6.2, 6.3 and 6.4 of the IGC Code and tables 7.2, 7.3 and 7.4 of the IGF Code, respectively, or by an IMO MSC circular.

3.3 *Equivalent alternative metallic materials*: Alternative metallic materials having chemical and mechanical properties that are equivalent or superior to those listed in tables 6.2, 6.3 and 6.4 of the IGC Code and tables 7.2, 7.3 and 7.4 of the IGF Code, respectively, that have been approved under these Guidelines.

3.4 *Other alternative metallic materials*: Alternative metallic materials having mechanical properties that do not meet those listed in tables 6.2, 6.3 and 6.4 of the IGC Code and tables 7.2, 7.3 and 7.4 of the IGF Code, respectively.

3.5 *Recognized standards*: Applicable international or national standards acceptable to the Administration, or standards laid down and maintained by the recognized organization.

3.6 *Administration*: Government of the State whose flag the ship is entitled to fly.

PART II
MATERIAL SPECIFICATIONS AND TESTING REQUIREMENTS

4 Material specification

4.1 All alternative metallic materials should have a recognized standard for cryogenic service for consideration under these Guidelines. The standard should cover specific forms of the material being approved, including plates, sections, castings, forgings or pipes, and should specify heat treatment and grain structure. The standard should meet the scope and general requirements of section 6.2 of the IGC Code. Micro-alloying elements not identified in the recognized standards may be considered subject to approval by the Administration.

4.2 Alternative metallic material, including plates, castings and forgings, should be joined using an approved method specified by a recognized standard. When applied, conventional welding procedures qualified in accordance with a recognized standard and complying with procedures contained in chapter 6.5 of the IGC Code and part B-1, section 16.3 of the IGF Code should be specified for the welding of alternative metallic materials. The welding procedures should specify heat input and pre- and post-weld heat treatment.

4.3 Welding procedures and non-destructive testing (NDT) should be specified for all alternative metallic materials. These procedures should conform to a recognized standard and comply with testing requirements specified in chapter 6.5 of the IGC Code and part B-1, section 16.3 of the IGF Code.

5 Testing

5.1 Test requirements are provided in the appendix to the Guidelines and are based upon section 6.3 of the IGC Code and part B-1, section 16.2 of the IGF Code.

5.2 Depending on the design temperature, Charpy V-notch tests should be conducted in accordance with the footnotes in the applicable tables given in chapter 6 of the IGC Code and section 7 of the IGF Code.

5.3 Subject to the approval of the Administration, consideration can be given to alternative test methods that provide an equivalent level of safety. Test requirements should not be waived unless there is a valid technical justification, or the material properties can be confirmed by another test method. Test requirements may be waived if not required for specific tank types within chapter 4 of the IGC Code, section 6 of the IGF Code or if not required for similar established metallic materials.

5.4 The testing of alternative metallic material should be conducted on at least one of the following forms: plates, castings, forgings or pipes. The testing of any form should meet the sampling and specimen position requirements of section 6.4 of the IGC Code and section 7.4 of the IGF Code. Initial testing should be conducted on the form reflecting the application of an alternative metallic material. Approval is limited to forms for which test results are provided; however, all forms do not have to be considered for approval of the alternative metallic material. If a waiver of requirements for post-weld heat treatment is sought, additional welded samples with the required post-weld heat treatment should be provided for comparison purposes.

5.5 Corrosion sensitization can occur in stainless and other austenitic steels. In such cases, the Administration may require additional corrosion testing such as an Intergranular Corrosion Test such as ASTM A262 and a Stress Corrosion Cracking Test such as ASTM G36 or ASTM G123.

6 Acceptance criteria

6.1 Test acceptance criteria are provided in the appendix to this Guideline and are based upon section 6.3 of the IGC Code and part B-1, section 16.2 of the IGF Code.

6.2 The application of an alternative metallic material in a specific design should be based upon the adequacy of the material for the design loads and the suitability of the material properties for their intended use in accordance with the design conditions specified in section 4.18 of the IGC Code and section 6.4.12 of the IGF Code.

6.3 Approval of alternative metallic materials should be for each form of the material for which there are satisfactory test results.

7 Novel design and equivalent arrangements

Alternative metallic materials may be used in the design of novel containment systems under section 4.27 of the IGC Code and section 6.4.16 of the IGF Code. Section 2.1 in appendix 5 of the IGC Code and part A-1 annex, section 2.1 of the IGF Code require the use of established metallic materials. The use of other alternative metallic materials should not be considered in a design.

PART III
APPLICATION

8 Approval procedures

8.1 Upon satisfactory completion of testing of the appropriate forms and acceptance of the results, an alternative metallic material is considered to be an accepted equivalent alternative metallic material for the purpose of the Guidelines.

8.2 The approval should specify any limitations that have been identified in the inherent properties of the approved alternative metallic material that may need to be considered in its use. These properties may include, but are not limited to:

.1 under-matching/over-matching of welds;

.2 pre- and post-weld heat treatment;

.3 corrosion;

.4 specific NDT requirements or limitations; and

.5 toxicity of welding fumes.

8.3 Tables 6.2, 6.3 and 6.4 of the IGC Code and tables 7.2, 7.3 and 7.4 of the IGF Code may be modified to incorporate new alternative metallic materials subject to the following:

.1 material should be qualified using these Guidelines;

.2 material compatibility for all intended cargoes should be demonstrated;

.3 relevant fabrication experience on any tank type on a ship should be documented;

.4 material should have minimum of five years of service experience on board a ship or equivalent to one special survey cycle;

.5 service experience should be on a ship in service, relevant to the material's future use; and

.6 if simulation is used, credit may be given to a reduced service period upon completion of the first intermediate survey. The scope of this survey should be in accordance with the requirements of the first special survey, including NDT, of the tank.

9 Application

The Administration should assign approved safety factors based upon those for nickel steels, carbon manganese steels, austenitic steels or aluminium alloys in the IGC and IGF Codes.

10 References

MSC.1/Circ.1599/Rev.3 *Interim guidelines on the application of high manganese austenitic steel for cryogenic service.*

APPENDIX 1

MATERIAL TESTING REQUIREMENTS AND ACCEPTANCE CRITERIA

1 Test of base material

1.1 **Material specifications**: Chemical composition and mechanical properties meeting a recognized standard for the alternative metallic material intended for cryogenic service.

Acceptance criteria: in accordance with the recognized standard.

1.2 **Micrographic examination**: The test should be carried out in accordance with section 6.3.4 of the IGC Code using recognized standards such as ASTM E112.

Acceptance criteria: Microstructure including grain size. The absence of precipitations, segregation and cracking should be reported. Acceptance should be to the satisfaction of the Administration.

1.3 **Tensile test**: The test should be carried out in accordance with section 6.3.1 of the IGC Code. Samples should be taken from three heats of different compositions, both at room and cryogenic temperatures equal to the minimum design temperature of the alternative metallic material. The number of samples should be sufficient to provide statistically valid results.

Acceptance criteria: The yield strength, tensile strength and elongation should be in accordance with the recognized standard for the chemical composition given in 1.1 of this appendix.

1.4 **Charpy impact test**: The test should be carried out in accordance with section 6.3.2 of the IGC Code. Samples should be taken from three heats of different compositions, both at room and cryogenic temperatures equal to the required test temperature. Impact tests should not be omitted for austenitic steels due to lack of experience. Test temperatures should be as follows:

Material thickness (mm)	Test temperature (ºC)
t < 25	5ºC below design temperature (ferritic steel only)
25 < t ≤ 30	10ºC below design temperature
30 < t ≤ 35	15ºC below design temperature
35 < t ≤ 40	20ºC below design temperature

Acceptance criteria: unless higher values are required by the material specification

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Material	Test piece	Minimum average energy (KV)
Ferrous alloy plates	Transverse	27 J
Ferrous alloy sections and forgings	Longitudinal	41 J
Non-Ferrous alloy		Not required, subject to the approval of the Administration

1.5 **Charpy impact test on strain aged specimens**: The test should be carried out in accordance with a recognized standard such as ASTM E23. Strain ageing consists of 5% deformation for one hour at 250°C in accordance with IACS UR W11. Samples should be taken from three heats of different compositions, both at room and cryogenic temperatures equal to the minimum test temperature. Impact tests should not be omitted for austenitic steels because of lack of experience. Test temperatures should be as follows:

Material thickness (mm)	Test temperature (°C)
t < 25	5°C below design temperature (ferritic steel only)
25 < t ≤ 30	10°C below design temperature
30 < t ≤ 35	15°C below design temperature
35 < t ≤ 40	20°C below design temperature

Acceptance criteria: unless higher values are required by the material specification.

Material	Test piece	Minimum average energy (KV)
Ferrous alloy plates	Transverse	27 J
Ferrous alloy sections and forgings	Longitudinal	41 J
Non-Ferrous alloy	-	Not required, subject to the approval of the Administration

1.6 **Drop weight test**: Applicable only for ferritic steels including ferritic-austenitic (duplex) grade. The aim of the test is to establish the nil ductility transition temperature (NDTT). Samples should be taken from three heats of different compositions, both at room and cryogenic temperatures equal to the minimum test temperature. The test should be carried out in accordance with a recognized standard such as ASTM E208 for ferritic steels.

Acceptance criteria: No break at 10°C below the design temperature.

1.7 **Fatigue test**: The basis for documenting adequate fatigue performance (S-N curves) should be in accordance with paragraph 4.18.2.4.2 of the IGC Code. The extent of fatigue testing is based on comparison with recognized S-N curves for metallic materials (such as IIW or DNVGL-RP-C203 or BS 7608).

The fatigue tests should be based on a minimum of five test samples at each stress level. For a "one slope S-N curve" a minimum of three stress levels should be tested. Additional stress levels are to be tested for "two slope S-N curves". As guidance, stress levels should be selected to achieve in the range of 10^5 to 10^8 cycles.

Acceptance criteria: The fatigue test results should be at least equal to or better than the reference S-N curve.

1.8 **CTOD (Crack Tip Opening Displacement) test**: The test should be carried out in accordance with a recognized standard such as ASTM E1820, BS 7448 or ISO 12135.

Acceptance criteria: CTOD minimum value should be in accordance with the design specification for testing at room and cryogenic temperatures equal to the minimum design temperature of the material. A minimum of three successful tests should be performed at room and cryogenic temperatures. As guidance a minimum CTOD value of 0.2 mm is often required.

1.9 **Corrosion test:** The type of corrosion tests to be applied will depend on the material, type of weld and the specific cargoes or fuels listed in the IGC or IGF Codes. The tests should include tests for general corrosion, intergranular corrosion and stress corrosion. The tests should be carried out in accordance with ASTM A262, ASTM G31, ASTM G36, ASTM G58, ASTM G123 or other relevant recognized standards. In the absence of a relevant recognized standard for the specific cargo or fuel, the test procedures should align with the general principles of corrosion tests that follow the recognized standards listed herein.

Acceptance criteria: In accordance with the relevant recognized standard approved by the Administration for the material's intended service. In the absence of a relevant recognized standard for the specific cargoes or fuels, the results should align with other recognized standards, and projected corrosion rates and test outcomes should be subject to the satisfaction of the Administration.

1.10 **Corrosion test for ammonia compatibility**: The additional test should be carried out in accordance with the test requirements set out in appendix 2 to qualify for ammonia service.

Acceptance criteria: should be in accordance with the acceptance criteria set out in appendix 2.

2 Test of welded condition (including HAZ)

2.1 **Micrographic examination**: The test should be carried out in accordance with section 6.3.4 of the IGC Code using recognized standards such as ASTM E112.

Acceptance criteria: Microstructure including grain size, absence of precipitations, segregation, and cracking should be reported. Acceptance should be to the satisfaction of the Administration.

2.2 **Hardness test**: The test should be carried out in accordance with section 6.3.4 and paragraph 6.5.3.4.5 of the IGC Code in accordance with recognized standards such as ISO 6507-1.

Acceptance criteria: The hardness value should be to the satisfaction of the Administration.

2.3 **Cross-weld tensile test**: This test should be carried out in accordance with paragraph 6.5.3.4.1 of the IGC Code. Recognized standards such as ASTM E8/E8M may be applied.

Acceptance criteria: In accordance with paragraph 6.5.3.5.1 of the IGC Code. The presence of under-matched welds should be considered for the intended application in accordance with paragraph 4.18.1.3.1.2 of the IGC Code.

2.4 **Charpy impact test**: This test should be carried out in accordance with section 6.3.2 and paragraph 6.5.3.4.4 of the IGC Code.

Acceptance criteria: In accordance with paragraph 6.5.3.5.3 of the IGC Code.

2.5 **CTOD (Crack Tip Opening Displacement) test**: The test should be carried out in accordance with a recognized standard such as ASTM E1820 or ISO 15653. The notch introduced in the test should be positioned in the microstructure with the lowest fracture toughness.

Acceptance criteria: CTOD minimum value should be in accordance with the design specification for testing at room and cryogenic temperatures equal to the minimum design temperature of the material. A minimum of three successful tests should be performed at room and cryogenic temperatures. As guidance a minimum CTOD value of 0.2 mm is often required.

2.6 **Ductile fracture toughness test (J_{Ic})**: The test should be carried out in accordance with a recognized standard such as ASTM E1820, ASTM E2818, ISO 15653 or ISO 12135. The notch introduced in the test should be positioned in the microstructure with the lowest fracture toughness. The ductile fracture toughness test may be carried out as an alternative to the CTOD test in 2.5 at the discretion of the Administration.

Acceptance criteria: In accordance with the recognized standard. A minimum of three successful tests should be performed at room and cryogenic temperatures.

2.7 **Bending test**: The test should be carried out in accordance with section 6.3.3 of the IGC Code.

Acceptance criteria: No fracture should be acceptable after a 180^{o} bend as required for welded material in accordance with paragraph 6.5.3.4.3 and 6.5.3.5.2 of the IGC Code.

2.8 **Fatigue test**: The basis for documenting adequate fatigue performance (S-N curves) should be in accordance with paragraph 4.18.2.4.2 of the IGC Code. The extent of fatigue testing is based on comparison with recognized S-N curves for metallic materials (such as IIW or DNVGL-RP-C203). The fatigue tests should be based on a minimum of five test samples at each stress level. For a "one slope S-N curve" a minimum of three stress levels should be tested. Additional stress levels to be tested for "two slope S-N curves". As guidance, stress levels should be selected to achieve in the range of 10^5 to 10^8 cycles.

Acceptance criteria: The fatigue test results should be at least equal to, or better than, the reference SN curve.

2.9 **Corrosion test**: The type of corrosion tests to be applied will depend on the material, type of weld and the specific cargoes or fuels listed in the IGC or IGF Codes. The tests should include tests for general corrosion, intergranular corrosion and stress corrosion. The tests should be carried out in accordance with ASTM A262, ASTM G31, ASTM G36, ASTM G58, ASTM G123 or other relevant recognized standards. In the absence of a relevant recognized standard for the specific cargo or fuel, the test procedures should align with the general principles of corrosion tests that follow the recognized standards listed herein.

Acceptance criteria: In accordance with the relevant recognized standard approved by the Administration for the material's intended service. In the absence of a relevant recognized standard for the specific cargoes or fuels, the results should align with other recognized standards, and projected corrosion rates and test outcomes should be subject to the satisfaction of the Administration.

2.10 **Corrosion test for ammonia compatibility**: The additional test should be carried out in accordance with the test requirements set out in appendix 2 to qualify for ammonia service.

Acceptance criteria: should be in accordance with the acceptance criteria set out in appendix 2.

APPENDIX 2

ADDITIONAL COMPATIBILITY TEST PROCEDURES FOR AMMONIA SERVICE

The test should be carried out in accordance with a recognized standard such as ASTM B858. This standard is applicable to copper alloys and not specifically to high manganese austenitic steel. Consequently, the following additional non-standard test should be performed:

1 Specimens should be prepared in accordance with standards ISO 7539-2 and ISO 16540. The specimens should be bent, prior to testing, using the four points bending test under constant strain. The total maximum strain of the sample should be equal to the yield strength of the material at atmospheric temperature. Strain gauges should be applied to measure the strain applied. In the case of welded specimens, strain gauges should be applied to each side of the welded joint. The sample should be constrained to maintain its form during testing. The details are described in specimen preparation.

2 A total of 36 specimens (three welded and three base metal at each ammonia environment) should each be immersed in the following four ammonia environments for a period of 30 days:

.1 liquid phase ammonia environments, obtained by cooling of ammonia at slightly lower temperature than the boiling temperature of ammonia e.g. -33.5^{o}C and at atmospheric pressure with the following liquid ammonia compositions:

.1 0.1% weight of water and 2.5 ppm of oxygen; and

.2 2.5 ppm of oxygen;

.2 gas phase ammonia environments at ambient temperature (+25^{o}C) and atmospheric pressure with the following gas ammonia compositions:

.1 pure ammonia (³99.99%); and

.2 0.9% volume of oxygen and 99.1%volume of ammonia;

.3 gas phase ammonia environments at -20^{0}C and atmospheric pressure with the following gas ammonia compositions:

.1 pure ammonia (³99.99%); and

.2 0.9% volume of oxygen and 99.1%volume of ammonia.

Stress corrosion cracking tests should be performed in agreement with requirements of standards ISO 7539 and ISO 16540.

3 Test report should provide all procedures, set up data, examinations, information about the environment, in agreement with standard ISO 16540 and include:

.1 the orientation, types, and dimensions of specimens;

.2 description of materials:

.1 chemistry and tensile properties of base plate;

.2 chemistry and tensile properties of welding consumables;

.3 type of welding, hardness of the weld metal and heat affected zones;

.4 four-point bending test set up data;

.5 target stress and applied deflection;

.6 strain measurement procedures;

.7 loading procedures; and

.8 test environment (temperature, water and oxygen content, and pH).

Test acceptance criteria

After immersion, all specimens should be examined for stress corrosion cracking under an optical microscope with proper magnification. The location and the number of cracks should be specified, and a fluorescent penetration test performed to confirm the results as necessary. For welded joints, the location of cracks should be described as located in the base metal, weldment or HAZ. If no superficial crack is observed, a longitudinal cut should be done at two different locations and a cross section examination with proper magnification should be performed. The presence of any corrosion pitting and the maximum depth should be reported. The results should be approved by the Administration.

Loading jig

The loading jig made of corrosion resistant alloys with spacing between outer rollers of 85 mm shown in figure 1 is to be used to apply a constant deflection to the specimen. The specimen is electrically isolated from the ceramic rollers in order to avoid undesirable galvanic corrosion.

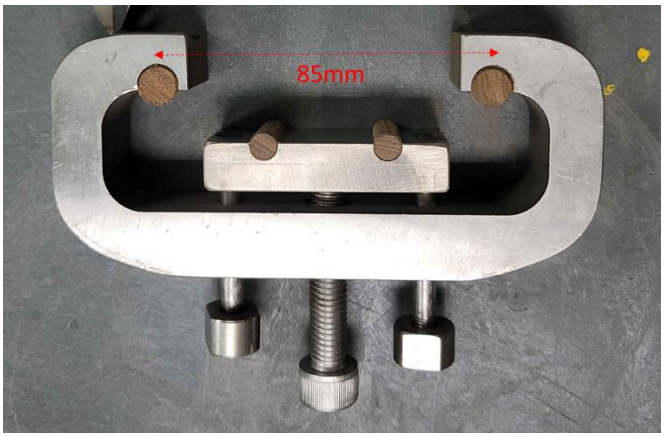

Figure 1: Four-point bend loading jig design

Specimen preparation

The specimens are machined from a 40 mm thick hot rolled plate and are not subjected to post-weld heat treatment. The outer radius of the specimen subject to bending is the original surface of the hot rolled plate. They are bent prior to testing and, surface would be exposed to ammonia in a tank, is not machined.

Four-point bend specimens are flat strips of uniform rectangular cross section and uniform thickness except in the case of testing welded specimens with one face in the as-welded condition as shown in figure 2. The original surface from a 40 mm hot rolled plate (cap bead in case of welded specimen) is the one to be observed. For weldments, the weld bead to be tested is the weld cap.

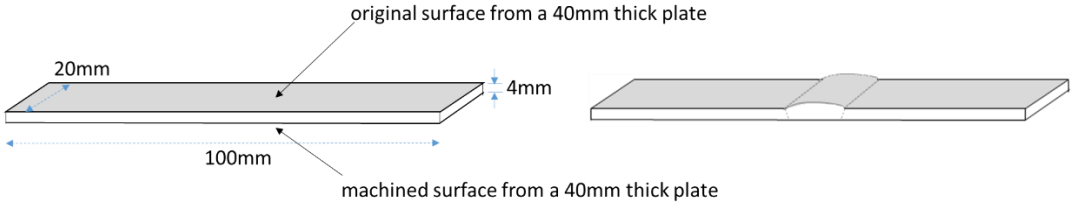

Figure 2: Four-point bend specimens (parent specimen and as-welded specimen)

Strain gauging

Dial gauge will be attached for measurement of deflection at the centre of the face in tension. The loading of the specimen is such that it reaches to the required yield strength level and then the specimen is constrained to maintain its form during testing. The amount of deflection, y, is set as the formula below complying with ISO 16540.

$$Y = \frac{(3H^2 - 4A^2)\sigma}{12Et}$$

where σ is the required stress (yield strength in this case), E is the modulus of elasticity, t is the specimen thickness, A is the distance between the inner and outer supports, and H is the distance between the outer supports. Prior to four-point bending, uniaxial tensile test of a 40 mm thick plate will be performed to determine the yield strength to be applied for the calculation of the amount of deflection required. For the simplicity of the welded specimen testing, the same amount of the deflection as for the parent plate is to be set out.