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REVISED GUIDELINES ON THE APPLICATION OF HIGH MANGANESE AUSTENITIC STEEL FOR CRYOGENIC SERVICE (MSC.1/CIRC.1599/REV.1)

1 Owing to the growing global demand for liquefied natural gas (LNG) as an environment-friendly energy source and the increased construction and operation of LNG-fuelled ships, the Maritime Safety Committee, at its ninety-sixth session (11 to 20 May 2016), agreed to the need to ensure that cargo and fuel tanks of LNG carriers and LNG-fuelled ships were safe, and hence tasked the Sub-Committee on Carriage of Cargoes and Containers with addressing the matter by developing amendments to the IGC and IGF Codes in order to include high manganese austenitic steel for cryogenic service.

2 The Maritime Safety Committee, at its 100th session (3 to 7 December 2018), acknowledging the increasing use of high manganese austenitic steel by the industry for cryogenic service and the need for guidance in this respect, approved the *Interim guidelines on the application of high manganese austenitic steel for cryogenic service* (MSC.1/Circ.1599).

3 The Maritime Safety Committee, at its 102nd session (4 to 11 November 2020), approved the Revised Interim Guidelines (MSC.1/Circ.1599/Rev.1), prepared by the Sub-Committee on Carriage of Cargoes and Containers, at its sixth session (9 to 13 September 2019).

4 The Maritime Safety Committee, at its 105th session (20 to 29 April 2022), approved the Revised Guidelines, as set out in the annex, prepared by the Sub-Committee on Carriage of Cargoes and Containers, at its seventh session (6 to 10 September 2021).

5 The Committee agreed to keep the Revised Guidelines under review, taking into account operational experience gained with their application.

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

7 This circular supersedes MSC.1/Circ.1599/Rev.1.

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ANNEX

REVISED GUIDELINES ON THE APPLICATION OF HIGH MANGANESE AUSTENITIC STEEL FOR CRYOGENIC SERVICE

Part I
General

1 Scope

These Guidelines on the application of high manganese austenitic steel for cryogenic service provide the designer and manufacturer with practical information on the design and construction of cargo and fuel tanks using high manganese austenitic steel for cryogenic service, to comply with the Design Conditions defined in section 4.18 of the IGC Code and section 6.4.12 of the IGF Code.

2 Application

2.1 These Guidelines are not intended to replace any requirements of the IGC and IGF Codes. They are intended as complementary requirements for the utilization of high manganese austenitic steel in the design and fabrication of cargo and fuel tanks complying with the IGC and IGF Codes subject to the following:

- .1 Application is suitable for the following cargoes and/or fuels if authorized by the IGC and IGF Codes:
  - .1 Butane (all isomers);
  - .2 Butane-propane mixture;
  - .3 Carbon Dioxide (High Purity and reclaimed quality);
  - .4 Ethane;
  - .5 Ethylene;
  - .6 Methane (LNG);
  - .7 Pentane (all isomers); and
  - .8 Propane.
- .2 Application is limited to plates (hot rolled) between 6 mm and 40 mm thick.

2.2 The application of high manganese austenitic steel for cargo and fuel tanks is limited by the requirements specified in the following.

3 Definitions

High manganese austenitic steel: Steel with a high amount of manganese in order to retain austenite as its primary phase at atmospheric and service temperature.

Under-matched welds: For welded connections where the weld metal has lower yield or tensile strength than the parent metal.

Part II
Material specifications and testing requirements

4 Material specification

4.1 The material specification should be submitted to the Administration for approval. The test requirements and acceptance criteria for the material are described in detail in the appendix.

4.2 The steel should be fully killed and fine-grained. The condition of supply for all material should be hot rolled with subsequent controlled cooling as necessary. The reduction ratio of slab to finished product thickness should not be less than 3:1. Other conditions of supply should be in accordance with those prescribed by the Administration.

4.3 The use of high manganese austenitic steel is limited to steel plates with a thickness between 6 mm and 40 mm. For thicknesses greater than 40 mm, special consideration may be given by the Administration. Other dimensions may be subject to acceptance by the Administration.

5 Chemical composition

The chemical composition for high manganese austenitic steel should meet the requirements of recognized standards, such as ASTM standard A1106/A1106M-17 as shown in table 1, or ISO 21635:2018.

Table 1: Chemical composition for high manganese austenitic steel
(Ref. ASTM standard A1106/A1106M-17)

	Chemical Composition (wt.%, product)								
	C	Si	Mn	P	S	Cr	Cu	B	N
Requirements	0.35 - 0.55	0.10 - 0.50	22.50 - 25.50	Max. 0.030	Max. 0.010	3.00 - 4.00	0.30 - 0.70	Max. 0.005	Max. 0.050

Note: Silicon (Si) may be less than 0.10 %, provided total aluminium is 0.03 % or higher, or provided acid soluble aluminium is 0.025 % or higher.

6 Mechanical properties

Mechanical properties for the base metal of high manganese austenitic steel should meet the requirements of the IGC and IGF Codes, as relevant, and also recognized standards applied to chemical composition, such as ISO 21635:2018 (refer to table 2 below) or ASTM A1106/A1106M-17. Compliance should also be documented in accordance with material testing requirements and acceptance criteria outlined in the appendix.

.1 Base metal

Table 2: Mechanical properties for base metal of high manganese austenitic steel
(Reference ISO 21635:2018)

Minimum yield strength (0.2 % offset) N/mm^2	**Tensile strength** N/mm^2	**Minimum elongation** % at $5.65\sqrt{S_0}$
400	800 to 970	22.0

(Note the impact test requirements as specified in table 6.3 of the IGC Code or table 7.3 of the IGF Code, as relevant)

.2 As welded condition

Table 3: Typical mechanical properties for "As welded condition"

Tensile properties		
Minimum yield strength (0.2 % offset) N/mm^2	**Minimum tensile strength** N/mm^2	**Minimum elongation** % at $5.65\sqrt{S_0}$
400	660	22.0

(Note the impact test requirements as specified in table 6.3 of the IGC Code or table 7.3 of the IGF Code, as relevant)

7 Welding of metallic materials and non-destructive testing

Welding of metallic materials and non-destructive testing should be in accordance with chapter 6 of the IGC Code or chapter 16 of the IGF Code. See "Material testing requirements and test acceptance criteria" as set out in the appendix. Typical minimum values of yield and tensile strength for welded conditions are shown in table 3.

8 Material testing and acceptance criteria

The material testing and applied acceptance criteria should be in accordance with chapter 6 of the IGC Code or chapter 16 of the IGF Code and the appendix. Compliance should also be documented in accordance with the material testing requirements and acceptance criteria outlined in the appendix.

9 Manufacturer approval scheme

Approval of the manufacturer should be carried out in accordance with section 6.2.2 of the IGC Code or section 16.1.1 of the IGF Code and to the satisfaction of the Administration.

Part III
Application

10 Design application

10.1 General

10.1.1 The relevant load conditions and design conditions should be established in accordance with section 4.18 of the IGC Code or section 6.4.12 of the IGF Code. Guidance on special considerations for high manganese austenitic steel is described below.

10.1.2 For the selection of relevant safety factors for high manganese austenitic steels (see paragraphs 4.21 to 4.23 of the IGC Code or section 6.4.15 of the IGF Code), the safety factors specified for "Austenitic Steels" should be applied both for the base material and for as welded condition.

10.2 Ultimate design condition
(Reference: section 4.18.1 IGC Code or section 16.3.3 IGF Code)

It should be noted that high manganese austenitic steels normally have under-matched welds and, therefore, it is of great importance that the design values of the yield strength and tensile strength are based on the "minimum mechanical properties" for the base material and as welded condition (see section 6 on Mechanical Properties). Note the limitation for under-matched welds defined in section 4.18.1.3.1.2 of the IGC Code or section 16.3.3.5.1 of the IGF Code.

10.3 Buckling strength

10.3.1 Buckling strength analysis should be carried out based on recognized standards. Functional loads as defined in section 4.3.4 of the IGC Code or section 6.4.1.6 of the IGF Code should be considered. Note that design tolerances should be considered where relevant and be included in the strength assessment as required in section 6.6.2.1 of the IGC Code or section 16.4.2 of the IGF Code.

10.3.2 It should be noted that the acceptance criteria for the flooding load cases are different from other buckling load cases. Furthermore, the acceptance criteria for flooding load cases, as defined in the IGC Code and the IGF Code, are also different, as the IGF Code requires the tank to "keep its integrity after flooding to ensure safe evacuation of the ship" (section 6.4.1.6.3.3 of the IGF Code), while the IGC Code only refers to endangering the integrity of the ship's hull (section 4.3.4.3.3 of the IGC Code).

10.4 Fatigue design condition (Reference: 4.18.2 IGC Code and 6.4.12.2 IGF Code)

The fatigue design curves for base material and for welded conditions have been documented as a comparison with recognized S-N curves, as provided by the D-curve in reference 11.4 (table 4) and FAT 90 provided by reference 11.5 (figure 1). Fatigue tests have been carried out for butt welded joints only. However, for other details, the application of other S-N curves should be to the satisfaction of the Administration. Section 4.18.2.4.2 of the IGC Code and section 6.4.12.2.4 of the IGF Code specify the design S-N curves to be based on a 97.6% probability of survival corresponding to the mean-minus-two-standard-deviation curves of relevant experimental data up to final failure.

S-N curve	*$N \le 10^7$ cycles*		*$N > 10^7$ cycles*	*Fatigue limit at 10^7 cycles (MPa) *)*	*Thickness exponent k*	*Structural stress concentration embedded in the detail (S-N class), see also equation (2.3.2)*
	m_1	$\log \bar{a}_1$	$\log \bar{a}_2$ $m_2 = 5.0$			
B1	4.0	15.117	17.146	106.97	0	
B2	4.0	14.885	16.856	93.59	0	
C	3.0	12.592	16.320	73.10	0.05	
C1	3.0	12.449	16.081	65.50	0.10	
C2	3.0	12.301	15.835	58.48	0.15	
D	3.0	12.164	15.606	52.63	0.20	1.00
E	3.0	12.010	15.350	46.78	0.20	1.13
F	3.0	11.855	15.091	41.52	0.25	1.27
F1	3.0	11.699	14.832	36.84	0.25	1.43
F3	3.0	11.546	14.576	32.75	0.25	1.61
G	3.0	11.398	14.330	29.24	0.25	1.80
W1	3.0	11.261	14.101	26.32	0.25	2.00
W2	3.0	11.107	13.845	23.39	0.25	2.25
W3	3.0	10.970	13.617	21.05	0.25	2.50
*) see also [2.11]						

Table 4: (S-N curves in air): High manganese austenitic steel has been documented to be equal or better than the D-curve (reference 11.4) for as welded condition without stress concentration from any structural details

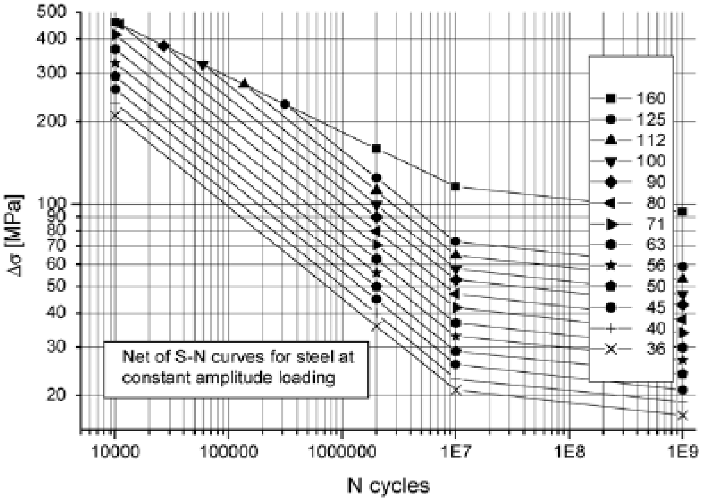


Figure 1: Reference S-N curve to high manganese austenitic steel is the FAT 90 curve (reference 11.5). The FAT 90 curve is as welded condition without stress concentration from any structural details.

10.5 Fracture mechanics analyses

10.5.1 For a cargo tank or fuel tank where a reduced secondary barrier is applied, fracture mechanics analysis should be carried out in accordance with the IGC or IGF Code.

10.5.2 Fracture toughness properties should be expressed using recognized standards. Depending on the material, fracture toughness properties determined for loading rates similar to those expected in the tank system should be required. The fatigue crack propagation rate properties should be documented for the tank material and its welded joints for the relevant service conditions. These properties should be expressed using a recognized fracture mechanics practice relating the fatigue crack propagation rate to the variation in stress intensity, ΔK, at the crack tip. The effect of stresses produced by static loads should be taken into account when establishing the choice of fatigue crack propagation rate parameters.

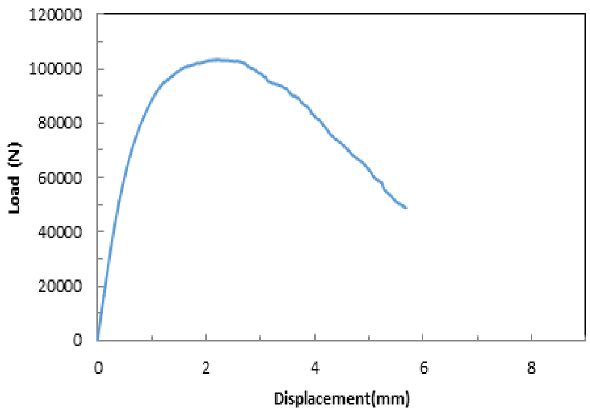
10.5.3 Note that for the application where very high static load utilization is relevant, alternative methods such as ductile fracture mechanic analyses should be considered.

10.5.4 An example of a typical Crack Tip Opening Displacement (CTOD) value at cryogenic condition can be found in figure 2.

10.5.5 A fracture mechanics analysis is required for type B tanks (section 4.22.4 of the IGC Code and section 6.4.15.2.3.3 of the IGF Code) where a reduced secondary barrier is applied. Fracture mechanics analysis may also be required for other tank types as found relevant to show compliance with fatigue and crack propagation properties. Note that CTOD values used in fracture mechanics analysis may in any case be an important property to analyse to ensure that materials are considered suitable for the application.

CTOD TEST REPORT					
			REPORT NO.		
Test Method Standard	**ISO 12135/15653 Specimen No.**		FCAW-2	**Test Date**	
Specimen configuration	**Square Cross-Section 3 Point Bend(W=B)**			**Crack plane orientation**	L-T
Specimen Dimensions		1	2	3	Average
	Thickness, B (mm)	40	40	40	40
	Width, W (mm)	80	80	80	80
	Span, S (mm)	320	**Knife edge thickness, z (mm)**		0
Test Material	**Young's Modulus of Elasticity, E (MPa)**			182,000	
	YS(0.2% proof), σ_{YSP} (MPa)			474	
	TS, σ_{TSP} (MPa)			780	
	YS(0.2% proof), σ_{YS} (MPa)			655	
	Machined Notch (mm)	**Width, N**	**Length, Lmc**	**Root Radius**	
		4.7	32.4	0.1	
Test Condition	**Temperature (℃)**			-165	

Test Result



Crack Length to Tip of Fatigue Pre crack (mm)									
a_1	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**	**a_7**	**a_8**	**a_9**	**a_0**
37.62	39.28	39.36	38.95	39.24	38.27	38.55	38.67	37.21	38.72
a_0/W		0.54		**Plastic Component of V, V_p (mm)**				1.53	
Critical CTOD (mm)									
Type of CTOD				**Total CTOD**					
δm				0.53					

Figure 2: Example of typical values for CTOD test at -165°C

10.6 Welding

10.6.1 Welding should be carried out in accordance with section 6.5 of the IGC Code or section 16.3 of the IGF Code, and to the satisfaction of the Administration.

10.6.2 For welding, the following points should be considered:

.1 for reducing the heat input during production:

.1 special attention should be given to the first root pass when applying flux-cored arc welding (FCAW); reduced amperage should be considered; and

.2 welding heat input of maximum 30 kJ/cm should be used as guidance for 3G position, as that has less heat input for 1G position;

.2 distance between the weld and nozzle should be kept to a minimum to reduce the oxygen content at the vicinity of the weld pool;

.3 weld gas composition of FCAW should normally be an 80/20 mix of argon and carbon dioxide; and

.4 appropriate ventilation should be provided to reduce exposure to hazardous welding fumes.

10.7 Non-destructive testing (NDT)

The scope of non-destructive testing (NDT) should be as required by section 6.5.6 of the IGC Code or section 16.3.6 of the IGF Code. NDT procedures should be in accordance with recognized standards to the satisfaction of the Administration. For high manganese austenitic steel suitable NDT procedures normally applicable for austenitic steels should be used.

10.8 Corrosion resistance

10.8.1 Appropriate measures with respect to corrosion protection and avoidance of a corrosive environment should be taken. Particularly for LNG fuel tanks that may not be in operation, appropriate precautions should be taken at all times to ensure that empty tanks are filled with inert gas or dry air when not in use.

11 References

ASTM A1106 / A1106M-17: Standard Specification for Pressure Vessel Plate, Alloy Steel, Austenitic High Manganese for Cryogenic Application

ISO 21635:2018 Ships and marine technology – Specification of high manganese austenitic steel used for LNG tanks on board ships

Material testing requirements and acceptance criteria (appendix)

DNVGL-RP-C203 Fatigue design of offshore steel structures

IIW 1823-07 Recommendations for fatigue design of welded joints and components

BS 7910:2013 + A1:2015 Guide to methods for assessing the acceptability of flaws in metallic structures

APPENDIX 1

MATERIAL TESTING REQUIREMENTS AND ACCEPTANCE CRITERIA FOR HIGH MANGANESE AUSTENITIC STEEL

1 Test of base material

1.1 Chemical composition

Recognized standards, such as ASTM A1106/A1106M-17 or ISO 21635:2018.

Test acceptance criteria

In accordance with recognized standards.

1.2 Micrographic examination

This test should be carried out in accordance with 6.3.4 of the IGC Code and 16.2.4 of the IGF Code, i.e. recognized standards, such as ASTM E112.

Test acceptance criteria

Microstructure to be reported for reference (i.e. grain size/precipitations).

1.3 Tensile test

This test should be carried out in accordance with 6.3.1 of the IGC Code and 16.2.1 of the IGF Code.
Samples should be taken from three heats of different compositions, both at room and cryogenic temperatures.

Test acceptance criteria

The yield, tensile strength and elongation should be in accordance with the recognized standard applied for Chemical composition (2.1) such as ASTM A1106/A1106M-17 or ISO 21635:2018.

1.4 Charpy impact test

This test should be carried out in accordance with 6.3.2 of the IGC Code and 16.2.2 of the IGF Code.

Test acceptance criteria

In accordance with table 6.3, as for austenitic steels, of the IGC Code and table 7.3 of the IGF Code.
Guidance note 9 of tables 6.3 and 7.3: Impact tests should not be omitted for high manganese austenitic steel owing to lack of experience.

1.5 Charpy impact test on strain aged specimens

Recognized standards, such as ASTM E23.

Test acceptance criteria

In accordance with table 6.3, as for austenitic steels, of the IGC Code and 16.2.2 of the IGF Code.

Guidance note 9 of tables 6.3 and 7.3 are not applicable for high manganese steel owing to lack of experience.

1.6 Drop weight test

Recognized standards should be applied, such as ASTM E208. Tests should be carried out at -196°C.

Test acceptance criteria

No break at test temperature as defined by the applied standard.

1.7 Fatigue test (S-N curve)

The basis for establishing S-N Curves should be in accordance with 4.18.2.4.2 of the IGC Code and 6.4.12.2.4 of the IGF Code.

Test acceptance criteria

S-N curves should be minimum the fatigue strength as established curves for steel as defined in IIW or DNVGL-RP-C203.

1.8 CTOD (crack tip opening displacement) test

Recognized standards, such as ASTM E1820, BS 7448 or ISO 12135, should be used for these purposes.

Test acceptance criteria

CTOD minimum value should be in accordance with design specification for testing at room and cryogenic temperatures as per design conditions. As ~~a~~ guidance a minimum CTOD value of 0.2 mm is often required.

1.9 Corrosion test

These tests should be carried out in accordance with recognized standards.

Test acceptance criteria

In accordance with recognized standard or approved by the Administration.

1.9.1 Intergranular corrosion test

This test should be carried out in accordance with recognized standard, such as ASTM A262.

Test acceptance criteria

In accordance with recognized standard or approved by the Administration.

1.9.2 General corrosion test

This test should be carried out in accordance with recognized standards, such as ASTM G31.

Test acceptance criteria

In accordance with recognized standard or approved by the Administration.

1.9.3 Stress corrosion cracking test

This test should be carried out to the satisfaction of the Administration, in accordance with recognized standards, such as ASTM G36 and ASTM G123.

Test acceptance criteria

In accordance with recognized standard or approved by the Administration.

1.9.4 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.
Test acceptance criteria In accordance with the acceptance criteria set out in appendix 2.

2 Tests of welded condition (including HAZ)

2.1 Micrographic examination This test should be carried out in accordance with 6.3.4 of the IGC Code and 16.2.4 of the IGF Code, i.e. recognized standards, such as ASTM E112 (or equivalent).
Test acceptance criteria Microstructure should be reported for reference (i.e. grain size/precipitations).

2.2 Hardness test This test should be carried out in accordance with 6.3.4 and 6.5.3.4.5 of the IGC Code and 16.2.4 and 16.3.3.4.5 of the IGF Code, i.e. recognized standards, such as ISO 6507-1.
Test acceptance criteria The hardness value should be reported for reference.

2.3 Cross-weld tensile test This test should be carried out in accordance with 6.5.3.5.1 of the IGC Code and 16.3.3.5.1 of the IGF Code as the relevant requirement for under-matched welds. Recognized standards, such as ASTM E8/E8M, should be applied.
Test acceptance criteria In accordance with 4.18.1.3.1.2 of the IGC Code and 6.4.12.1.1.3 of the IGF Code.

2.4 Charpy impact test This test should be carried out in accordance with 6.3.2 and 6.5.3.4.4 of the IGC Code and 16.2.2 and 16.3.3.4.4 of the IGF Code.
Test acceptance criteria In accordance with 6.5.3.5.3 of the IGC Code and 16.3.3.5.3 of the IGF Code.

2.5 CTOD (crack tip opening displacement) test Recognized standards, such as ASTM E1820, BS 7448 or ISO 15653, should be used for these purposes.
Test acceptance criteria CTOD minimum value should be in accordance with design specification for testing at room and cryogenic temperatures as per design conditions. As a guidance a minimum CTOD value of 0.2 mm is often required.

2.6 Ductile fracture toughness test, Jlc Recognized standards, such as ASTM E1820 or ISO 15653. The ductile fracture toughness test may be omitted at the discretion of the Administration.
Test acceptance criteria In accordance with recognized standard.

2.7 Bending test This test should be carried out in accordance with 6.3.3 of the IGC Code and 16.2.3 of the IGF Code.
Test acceptance criteria No fracture should be acceptable after a 180° bend as required for welded material as per 6.5.3.5.2 of the IGC Code and 16.3.3.5.2 of the IGF Code.

2.8 Fatigue test (S-N curve) The basis for establishing S-N Curves should be in accordance with 4.18.2.4.2 of the IGC Code and 6.4.12.2.4 of the IGF Code.
Test acceptance criteria S-N curves should be minimum the fatigue strength as established curves for steel as defined in IIW or DNVGL-RP-C203.

2.9 Corrosion test These tests should be carried out in accordance with recognized standards.
Test acceptance criteria In accordance with recognized standard or approved by the Administration.
2.9.1 Intergranular corrosion test This test should be carried out in accordance with recognized standard, such as ASTM A262.
Test acceptance criteria In accordance with recognized standard or approved by the Administration.

2.9.2 General corrosion test This test should be carried out in accordance with recognized standards, such as ASTM G31.
Test acceptance criteria In accordance with recognized standard or approved by the Administration.
2.9.3 Stress corrosion cracking test This test should be carried out to the satisfaction of the Administration, in accordance with recognized standard, such as ASTM G36, ASTM G58 and ASTM G123.
Test acceptance criteria In accordance with recognized standard or approved by Administration.
2.9.4 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.
Test acceptance criteria In accordance with the acceptance criteria set out in appendix 2.

REFERENCES:

ASTM E466-15 *Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials*

ASTM E1290-08e1 *Standard Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement (Withdrawn 2013)*
ASTM G31 *Standard Guide for Laboratory Immersion Corrosion Testing of Metals*.

ASTM B858 *Standard Test Method for Ammonia Vapor Test for Determining Susceptibility to Stress Corrosion Cracking in Copper Alloys*

ISO 12737:1999 *Metallic materials – Determination of plane-strain fracture toughness*[1]

ISO 15653:2018 *Metallic materials – Method of test for the determination of quasistatic fracture toughness of welds*[2]

IIW 1823-07 *Recommendations for fatigue design of welded joints and components*

ISO 12135:2016 *Metallic materials – Unified method of test for the determination of quasistatic fracture toughness*

ISO 15653:2018 Metallic materials – *Method of test for the determination of quasistatic fracture toughness of welds*

1 Replace ASTM E1820-18 Standard Test Method for Measurement of Fracture Toughness, BS 7448 1:1991 – Fracture mechanics toughness tests. Method for determination of KIc, critical CTOD and critical J values of metallic materials.

2 Supersede BS 7448-2 – Fracture Mechanics Toughness Tests: Method for Determination of KIc, Critical CTOD and Critical J Values of Welds in Metallic Materials.

APPENDIX 2

ADDITIONAL COMPATIBILITY TEST REQUIREMENTS 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.

.2 Two specimens (one welded and one base metal) 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 below liquefaction temperature 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 and atmospheric pressure with the following compositions:

.1 pure ammonia; 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 four points bending test set up data;

.3 target stress and applied deflection;

.4 strain measurement procedures;

.5 loading procedures; and

.6 test environment.

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 dye penetrant 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.

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