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GUIDELINES FOR APPLICATION OF THICK HIGHER STRENGTH STEEL PLATES FOR SHIPS

2024

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Beijing

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Chapter 1 General

1.1 Application

1.1.1 The Guidelines apply to approval and inspection of higher strength hull structural EH47 steels, and define the requirements on higher strength hull structural steels with a specified minimum yield strength of 460 N/mm^2.

1.1.2 The Guidelines apply to approval and inspection of higher strength hull structural EH36/EH40/EH47 steels with crack arrest properties, and define the requirements on brittle crack arrest steels with a specified minimum yield strength of 355 N/mm^2, 390 N/mm^2 and 460 N/mm^2.

1.1.3 The Guidelines identify when measures for the prevention of brittle fracture of extremely thick higher strength hull structural steel plates are required for longitudinal structural members in the upper deck region of container carriers.

1.2 Terms and definitions

1.2.1 Terms and definitions used in the Guidelines are as follows:

(1) Extremely thick steel plates mean steel plates with thickness over 50 mm and not greater than 100 mm.

(2) EH 47 steels mean higher strength hull structural EH steels with a specified minimum yield strength of 460 N/mm^2.

(3) Brittle crack arrest steels (BCA steels) are defined as steel plate with the specified brittle crack arrest properties measured by either the brittle crack arrest toughness K_{ca} or Crack Arrest Temperature (CAT), consisting of two brittle crack arrest properties, i.e. BCA 1 and BCA 2.

(4) The upper deck region of container ships means the upper deck plating, hatch side coaming plating, hatch coaming top plating and their attached longitudinals.

Chapter 2 EH47 Steels

2.1 General requirements

2.1.1 This Chapter defines the requirements on higher strength hull structural EH47 steels with a specified minimum yield strength of 460 N/mm^2.

2.1.2 The EH47 steels can be applied to longitudinal structural members in the upper deck region of container carriers (such as hatch side coaming, hatch coaming top and the attached longitudinals, etc.). Special consideration is to be given by CCS to the application of EH47 steels for other hull structures.

2.1.3 This Chapter gives the requirements for EH 47 steels in thickness greater than or equal to 50 mm and not greater than 100 mm intended for the upper deck plating and hatch coaming plating of container carriers. For EH 47 steels outside scope of the said thickness range, special consideration is to be given by CCS.

2.1.4 Unless otherwise specified in the Guidelines, EH47 steels are to satisfy relevant requirements in Section 3 Higher strength hull structural steels, Chapter 3 of PART ONE of CCS Rules for Materials and Welding and those for higher strength hull structural EH steels in CCS Guidelines for Inspection of Marine Rolled Steel Products (W01).

2.2 Technical conditions of EH47 steels

2.2.1 Chemical composition and deoxidation practice for EH47 steels are to satisfy the requirements of Table 2.2.1.

Chemical composition and deoxidation practice for EH47 steels without specified brittle crack arrest properties

Table 2.2.1

Grade	EH47
Deoxidation Practice	Killed and fine grain treated
Chemical Composition % (ladle samples)⑥⑦	
C max.	0.18
Mn	0.90 – 2.00
Si max.	0.55
P max.	0.020
S max.	0.020
Al (acid soluble min)	0.015①②
Nb	0.02 – 0.05②③
V	0.05 – 0.10②③
Ti max.	0.02②③
Cu max.	0.35
Cr max.	0.25
Ni max.	1.0
Mo max.	0.08

Ceq max.(4)	0.49
Pcm max.(5)	0.22

① The total aluminium content may be determined instead of the acid soluble content. In such cases the total aluminium content is to be not less than 0.020%.

② The steel is to contain aluminium, niobium, vanadium or other suitable grain refining elements, either singly or in any combination. When used singly the steel is to contain the specified minimum content of the grain refining element. When used in combination, the specified minimum content of a fine graining element is not applicable.

③ The total niobium, vanadium and titanium content is not to exceed 0.12%.

④ The carbon equivalent Ceq value is to be calculated from the ladle analysis using the following formula:

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad (\%)$$

⑤ Cold cracking susceptibility Pcm value is to be calculated using the following formula:

$$P_{cm}=C+\frac{Si}{30}+\frac{Mn}{20}+\frac{Cu}{20}+\frac{Ni}{60}+\frac{Cr}{20}+\frac{Mo}{15}+\frac{V}{10}+5B \quad (\%)$$

⑥ Where additions of any other element have been made as part of the steelmaking practice subject to approval by CCS, the content is to be indicated on product inspection certificate.

⑦ Variations in the specified chemical composition may be allowed subject to approval of CCS.

2.2.2 Conditions of supply and mechanical properties for EH47 steels are to satisfy the requirements of Table 2.2.2.

Conditions of supply and mechanical properties for EH47 steels①

Table 2.2.2

Supply condition	Grade	Yield Strength R_{eH} (N/mm^2) min.	Tensile Strength Rm (N/mm^2)	Elongation A_5 (%) min.	Charpy V-notch impact test			
					Test Temp. (℃)	Average Impact Energy (J) min.		
						50 ⩽ t ⩽ 70	70＜t⩽85	85＜t⩽100
						Longitudinal	Longitudinal	Longitudinal
TMCP②	EH47	460	570～720	17	-40	53	64	75

t: thickness (mm)

① The additional requirements for EH47 steel with brittle crack arrest properties is specified in Chapter 3 of the Guidelines.

② Other conditions of supply are to be specially considered by CCS.

2.3 Works approval of EH47 steels

2.3.1 Works approval of EH47 steels is to be carried out in accordance with the requirements of Annex 1.

2.4 Welding consumables of EH47 steels

2.4.1 Unless otherwise specified in the Guidelines, welding consumables of EH47 steels are to satisfy relevant requirements in Chapter 2 Welding Consumables of PART THREE of CCS Rules for Materials and Welding and those in CCS Guidelines for Inspection of Products of Welding Consumables (J01).

2.4.2 Mechanical properties for deposited metal tests for welding consumables are to satisfy the requirements of Table 2.4.2.

Mechanical properties for deposited metal tests for welding consumables

Table 2.4.2

Grade of welding consumables	Mechanical Properties			Charpy V-notch impact test	
	Yield Strength (N/mm^2) min.	Tensile Strength (N/mm^2)	Elongation (%) min.	Test Temp. (°C)	Average Impact Energy (J) min.
3Y47	460	570 - 720	19	-20	64
4Y47				-40	
5Y47				-60	

2.4.3 Mechanical properties for butt weld tests for welding consumables are to satisfy the requirements of Table 2.4.3.

Mechanical properties for butt weld tests for welding consumables

Table 2.4.3

Grade of welding consumables	Tensile Strength (N/mm^2)	Bend test ratio: $\frac{D}{t}$	Charpy V-notch impact test	
			Test Temp. (°C)	Average Impact Energy (J) min.
3Y47	570 - 720	4	-20	64
4Y47			-40	
5Y47			-60	

Note: The bending angle is to be 120°. After testing, the test specimens are not to reveal any open defects in any direction greater than 3 mm.

2.4.4 Diffused hydrogen content of EH47 welding consumables is to be of H5 or H10 level.

2.5 Welding procedure approval test of EH47 steels

2.5.1 Unless otherwise specified in the Guidelines, approval test items, test methods and acceptance criteria are to satisfy relevant requirements in Chapter 3 of PART THREE of CCS Rules for Materials and Welding.

2.5.2 The approval range of welding procedures for EH47 steels is to be in accordance with the requirements of Chapter 3 of PART THREE of CCS Rules for Materials and Welding, but the base metal can only cover EH47.

2.5.3 The number and sampling position of impact specimen are to be in accordance with the requirements of Section 2, Chapter 3 of PART THREE of CCS Rules for Materials and Welding. 64J at -20°C is to be satisfied.

2.5.4 Hardness test is to be in accordance with the requirements of Section 2, Chapter 1 of PART THREE of CCS Rules for Materials and Welding. HV10 is to be not more than 350. Measurement points are to include mid-thickness position in addition to the points required by Section 2, Chapter 1 of PART THREE of CCS Rules for Materials and Welding.

2.5.5 Tensile strength in transverse tensile test is to be not less than 570 N/mm^2.

2.5.6 CTOD test (weld center or grain coarsened HAZ) or deep notch test may be required. CTOD test methods are to be in accordance with the requirements of Section 8, Chapter 2 of PART ONE of CCS Rules for Materials and Welding. The test temperature is -10℃. It is recommended that the average value is not less than 0.15 mm.

2.5.7 The bend test pressure head diameter $D=5t$ (where t is thickness of test specimens), and the bending angle is to be 180°.

2.5.8 The macro examination is to reveal a regular weld profile, full penetration and the absence of defects such as cracks and lack of fusion.

2.6 Welding of EH47 steels

2.6.1 Welders engaged in EH47 welding work are to possess welder's qualifications issued or accepted by CCS.

2.6.2 Short bead length for tack and repairs of welds by welding are not to be less than 50 mm. In the case where P_{cm} is less than or equal to 0.19, 25 mm of short bead length may be adopted with approval of CCS.

2.6.3 Preheating is to be 50℃ or over when air temperature is 5℃ or below. In the case where P_{cm} is less than or equal to 0.19 and the air temperature is below 5℃ but above 0℃, alternative preheating requirements may be adopted with approval of CCS.

2.6.4 EH47 steel is to be welded according to Table 2.6.4 with a matching grade of welding consumables.

Welding consumables matching EH47 steel Table 2.6.4

Base metal	Thickness		
	50mm ≤ t ≤ 70mm	70 mm< t ≤ 85mm	85mm < t ≤ 100mm
Welding consumables	3Y47 4Y47 5Y47	4Y47 5Y47	5Y47

2.6.5 Special care is to be paid to the final welding so that harmful defects do not remain. Jig mountings are to be completely removed with no defects in general, otherwise the treatment of the mounting is to be accepted by CCS.

2.6.6 Steels used for run-on and run-off tabs and backing plates are not to have any significant impact on the weld. It is recommended to use materials same as or similar to the base metal.

Chapter 3 Brittle Crack Arrest Steels

3.1 General requirements

3.1.1 This Chapter defines the requirements on brittle crack arrest steels.

3.1.2 Crack arrest steels mean higher strength hull structural steels with a specified minimum yield strength of 355 N/mm^2, 390 N/mm^2 and 460 N/mm^2 which satisfy the requirements of this Chapter.

3.1.3 The application of brittle crack arrest steels is to comply with the requirements of Chapter 4 of the Guidelines, which covers longitudinal structural members in the upper deck region of container carriers (such as hatch side coaming, upper deck, hatch coaming top and the attached longitudinals, etc.).

3.1.4 The thickness range of brittle crack arrest steels is greater than or equal to 50 mm and not greater than 100 mm as specified in Table 3.2.2.

3.1.5 Unless otherwise specified in the Guidelines, crack arrest steels are to satisfy relevant requirements in Section 3 Higher strength hull structural steels, Chapter 3 of PART ONE of CCS Rules for Materials and Welding and those for higher strength hull structural EH steels in CCS Guidelines for Inspection of Marine Rolled Steel Products (W01).

3.2 Technical conditions of brittle crack arrest steels

3.2.1 Chemical composition and deoxidation practice for brittle crack arrest steels are to satisfy the requirements of Table 3.2.1.

Chemical composition and deoxidation practice for brittle crack arrest steels

Table 3.2.1

Grade	EH36-BCA	EH40-BCA	EH47-BCA
Deoxidation practice	Killed and fine grain treated		
Chemical composition % ①⑦⑧ (ladle samples)			
C max.	0.18		0.18
Mn	0.90 – 2.00		0.90 – 2.00
Si max.	0.50		0.55
P max.	0.020		0.020
S max.	0.020		0.020
Al (acid soluble min)	0.015 ②③		0.015 ②③
Nb	0.02 – 0.05 ③④		0.02 – 0.05 ③④
V	0.05 – 0.10 ③④		0.05 – 0.10 ③④
Ti max.	0.02④		0.02④
Cu max.	0.50		0.50
Cr max.	0.25		0.50
Ni max.	2.0		2.0
Mo max.	0.08		0.08

Ceq max.⑤	0.47	0.49	0.55
Pcm max.⑥	-		0.24

Notes:

① Chemical composition of brittle crack arrest steels is to comply with this Table, regardless of chemical composition specified in Section 3, Chapter 3 of PART ONE of CCS Rules for Materials and Welding and Table 2.2.1, Chapter 2 of the Guidelines.

② The total aluminium content may be determined instead of the acid soluble content. In such cases the total aluminium content is to be not less than 0.020%.

③ The steel is to contain aluminium, niobium, vanadium or other suitable grain refining elements, either singly or in any combination. When used singly the steel is to contain the specified minimum content of the grain refining element. When used in combination, the specified minimum content of a fine graining element is not applicable, but the approved technical conditions are to be met.

④ The total niobium, vanadium and titanium content is not to exceed 0.12%.

⑤ The carbon equivalent Ceq value is to be calculated from the ladle analysis using the following formula:

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad (\%)$$

⑥ Cold cracking susceptibility Pcm value is to be calculated using the following formula:

$$P_{cm}=C+\frac{Si}{30}+\frac{Mn}{20}+\frac{Cu}{20}+\frac{Ni}{60}+\frac{Cr}{20}+\frac{Mo}{15}+\frac{V}{10}+5B \quad (\%)$$

⑦ Where additions of any other element have been made as part of the steelmaking practice subject to approval by CCS, the content is to be indicated on product inspection certificate.

⑧ Variations in the specified chemical composition may be allowed subject to approval of CCS.

3.2.2 Brittle crack arrest steels are to satisfy the requirements of Tables 3.2.1 and 3.2.2. At the same time, EH36 and EH40 mechanical properties are to satisfy Section 3 Higher strength hull structural steels, Chapter 3 of PART ONE of CCS Rules for Materials and Welding, and EH47 mechanical properties are to satisfy the requirements of Table 2.2.2, Chapter 2 of the Guidelines. In addition, the tensile performance of thickness center of crack arrest steels is also to satisfy requirements.

Requirement of brittle crack arrest properties for brittle crack arrest steels

Table 3.2.2

Suffix to the steel grade①	Thickness range (mm)	Brittle crack arrest properties②⑥	
		Brittle Crack Arrest Toughness Kca at -10 °C (N/mm3/2) ③④	Crack Arrest Temperature CAT (°C) ④
BCA1	50 ≤ t ≤ 100	≥6,000 min.	≤-10
BCA2	80 ＜t ≤ 100⑦	≥8,000 min.	⑤

Notes:

① Suffix “BCA1” or “BCA2” is to be affixed to the steel grade designation (e.g. EH40-BCA1, EH47-BCA1, EH47-BCA2, etc.).

② Brittle crack arrest properties for brittle crack arrest steels are to be verified by either the brittle crack arrest toughness K_{ca} or Crack Arrest Temperature (CAT).

③ K_{ca} value is to be obtained by the brittle crack arrest test specified in Annex 3.

④ CAT is to be obtained by the test method specified in Annex 4.

⑤ Criterion of CAT for brittle crack arrest steels corresponding to K_{ca}=8,000 N/mm$^{3/2}$ is to be approved by CCS.

⑥ Where small-scale alternative tests are used for product testing (batch release testing), these test methods are to be approved by CCS according to Annex 5.

⑦ Lower thicknesses may be approved at the discretion of CCS.

3.2.3 The brittle crack arrest properties specified in Table 3.2.2 are to be evaluated for the products in accordance with the procedure approved by CCS (approval is to be in accordance with K_{ca} test of Annex 3 or CAT test of Annex 4, and delivery survey is to be in accordance with the small size test approved by CCS). For delivery survey, test specimens are to be taken from each piece (means "the rolled product from a single slab or ingot if this is rolled directly into plates").

3.3 Works approval of brittle crack arrest steels

3.3.1 Works approval of crack arrest steels is to be carried out in accordance with the requirements of Annex 2.

3.4 Welding procedure approval test of brittle crack arrest steels

3.4.1 Where Welding Procedure Specification (WPS) for the non-BCA steels has been approved, the said WPS is applicable to the same welding procedure applied to the same grade with suffix "BCA1" or "BCA2" except high heat input processes over 50 kJ/cm.

3.4.2 For EH36 and EH40 steel with crack arrest properties, the requirements for welding procedure qualification test are to be in accordance with the relevant requirements for each steel grade excluding suffix "BCA1" or "BCA2".

3.4.3 For EH47 steels with brittle crack arrest properties, HV10 is to be not more than 380. Measurement testing is to be in accordance with the provisions of PART THREE of CCS Rules for Materials and Welding. Measurement points are to include mid-thickness position in addition to the points required by CCS Rules for Materials and Welding. Other requirements for welding procedure qualification test of EH47BCA steel are to meet the welding procedure requirements for EH47 steel.

3.5 Welding of brittle crack arrest steels

3.5.1 Welding work (such as relevant welder's qualification, short bead, preheating, selection of welding consumable, etc.) for brittle crack arrest steels is to be in accordance with the relevant requirements for each steel grade excluding suffix "BCA1" or "BCA2".

3.5.2 Steels used for run-on and run-off tabs and backing plates are not to have any significant impact on the weld. It is recommended to use materials same as or similar to the base metal.

Chapter 4 Application of Extremely Thick Steel Plates in Container Ships

4.1 General requirements

4.1.1 This Chapter is to be complied with for container ships incorporating extremely thick steel plates having steel grade and thickness in accordance with 4.2 and 4.3 respectively.

4.1.2 This Chapter identifies when measures for the prevention of brittle fracture of extremely thick steel plates are required for longitudinal structural members.

4.1.3 This Chapter defines the following methods to apply to the extremely thick plates of container ships for preventing the crack initiation and propagation:

(1) Non-Destructive Testing (NDT) during construction detailed in 4.5;

(2) Periodic NDT after delivery detailed in 4.6;

(3) Brittle crack arrest design detailed in 4.7.

The application of the measures specified in 4.5, 4.6 and 4.7 is to be in accordance with Annex 6.

4.1.4 This Chapter gives the basic concepts for application of extremely thick steel plates to longitudinal structural members in the upper deck region of container ships.

4.1.5 For the application of this Chapter, the upper deck region means the upper deck plating, hatch side coaming plating, hatch coaming top plating and their attached longitudinals.

4.2 Steel grade

4.2.1 This Chapter is to be applied when any of H36, H40 and H47 steel plates are used for the longitudinal structural members in the upper deck region. H36, H40 and H47 refers to the minimum specified yield strength of steel 355, 390 and 460 N/mm^2, respectively.

4.2.2 In case H47 steel plates are used for longitudinal structural members in the upper deck region, the steel plates are to be of EH47 grade as specified in Chapter 2.

4.3 Thickness

4.3.1 For steel plates with thickness of over 50 mm and not greater than 100 mm, the measures for prevention of brittle crack initiation and propagation specified in 4.5, 4.6 and 4.7 are to be taken.

4.3.2 For steel plates with thickness exceeding 100 mm, appropriate measures for prevention of brittle crack initiation and propagation are to submit theoretical analysis and extra large size test results, subject to special consideration by CCS.

4.4 Hull structures (for the purpose of design)

4.4.1 The material factors of minimum specified yield strength of steel 355 and 390 N/mm^2 are given in PART TWO of CCS Rules for Classification of Sea-going Steel Ships. The material factor of EH47 steel for the assessment of hull girder strength is to be taken as $K = 0.62$.

4.4.2 The fatigue assessment of the longitudinal structural members is to be performed in accordance with the relevant requirements of CCS Guidelines for Fatigue Strength of Ship Structure.

4.4.3 Where extremely thick steel plates are applied to connections between outfitting and hull

structures, the edges are to be smoothly transitioned.

4.5 Non-Destructive Testing during construction (Measure No.1 of Annex 6)

4.5.1 Where non-destructive testing (NDT) during construction is required in Annex 6, the NDT is to be in accordance with 4.5.2 to 4.5.4. Time-of-Flight Diffraction (TOFD) or Phased Array Ultrasonic Testing (PAUT) techniques as specified in 4.9.1(2)(e) are to be carried out in accordance with the requirements of CCS Rules for Materials and Welding.

4.5.2 100% visual inspection and 100% ultrasonic testing (UT) are to be carried out on all block-to-block butt joints of all upper flange longitudinal structural members in the cargo hold region in accordance with Appendix 1 of PART THREE of CCS Rules for Materials and Welding. Upper flange longitudinal structural members include the topmost strakes of the inner hull/bulkhead, the sheer strake, main deck, coaming plate, coaming top plate, and all attached longitudinal stiffeners. These members are defined in Figure 4.5.2.

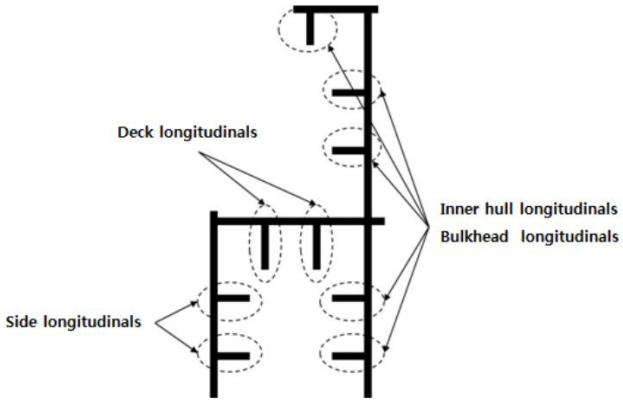

Figure 4.5.2 Upper Flange Longitudinal Structural Members

4.5.3 Acceptance criteria of UT are not to be lower than ISO 11666 level 2, EN ISO 11666 level 2, CB/T 3559 level II, JIS Z3060 level II or the requirements of other equivalent standards.

4.5.4 The acceptance criteria may be adjusted under consideration of the appertaining brittle crack initiation prevention procedure and the UT procedure is to be amended accordingly to a more severe sensitivity, subject to special agreement of CCS.

4.5.5 If Time-of-Flight Diffraction (TOFD) or Phased Array Ultrasonic Testing (PAUT) technique mentioned in 4.9.1(2)(e) is adopted, the requirements of Appendix 2 of PART THREE of CCS Rules for Materials and Welding are to be met. Acceptance criteria of Time-of-Flight Diffraction (TOFD) are not to be lower than ISO 15626 level 1, and acceptance criteria of Phased Array Ultrasonic Testing (PAUT) are not to be lower than ISO 19285 level 2.

4.6 Periodic NDT after delivery (Measure No.2 of Annex 6)

4.6.1 Where periodic NDT after delivery is required, the NDT is to be in accordance with 4.6.2 to 4.6.4.

4.6.2 The procedure of the NDT is to be in accordance with the requirements of Appendix 1[①] of PART THREE of CCS Rules for Materials and Welding.

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① For the purpose of the Guidelines, the requirements of Appendix 1 of PART THREE of CCS Rules for Materials and Welding apply to NDT of ships in service.

4.6.3 100% ultrasonic testing is to be carried out on all block-to-block butt joints of all upper flange longitudinal structural members in the cargo hold region (see 4.5.2) every five years.

4.6.4 Where UT is carried out, acceptance criteria of UT are not to be lower than ISO 11666 level 2, EN ISO 11666 level 2, CB/T 3559 level II, JIS Z3060 level II or the requirements of other equivalent standards.

4.6.5 Where Time-of-Flight Diffraction (TOFD) or Phased Array Ultrasonic Testing (PAUT) technique is carried out, acceptance criteria of Time-of-Flight Diffraction (TOFD) are not to be lower than ISO 15626 level 1, and acceptance criteria of Phased Array Ultrasonic Testing (PAUT) are not to be lower than ISO 19285 level 2.

4.7 Brittle crack arrest design (Measures No.3, 4 and 5 of Annex 6)

4.7.1 The brittle crack arrest steel method detailed in the Guidelines may be used when the measures No.3, 4 and 5 of Annex 6 are applied and the steel grade material of the upper deck is not higher than H40.

4.7.2 Measures for prevention of brittle crack propagation, are to be taken within the cargo hold region. A brittle crack arrest design means a design using these measures.

4.7.3 The measures given in the Guidelines generally apply to the block-to-block joints but it is to be noted that cracks can initiate and propagate away from such joints. Therefore, appropriate measures are also to be considered for the cases specified in 4.8.1 (b) (ii).

4.7.4 Brittle crack arrest steels are defined in Chapter 3 of the Guidelines.

4.8 Brittle crack arrest design

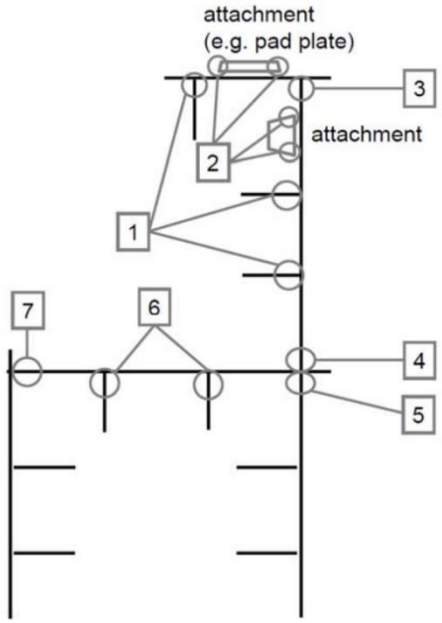
4.8.1 The purpose of the brittle crack arrest design is to arrest propagation of a crack at a proper position and to prevent large scale fracture of the hull girder.

(a) The locations of most concern for brittle crack initiation and propagation are the blockto-block butt weld joints either on hatch side coaming or on upper deck plating. Other locations in block fabrication where joints are aligned may also present higher opportunity for crack initiation and propagation along butt weld joints.

(b) Both of the following cases are to be considered:

(i) where the brittle crack runs straight along the butt joint; and

(ii) where the brittle crack initiates in the butt joint but deviates away from the weld and into the plate, or where the brittle crack initiates from any other weld (see Figure 4.8.1 for definition of other welds) and propagates into the plate.



"Other weld" includes the following:

① Fillet weld between hatch side coaming plating, including top plating, and longitudinals;

② Fillet weld between hatch side coaming plating, including top plating and longitudinals, and attachments. (e.g., Fillet weld between hatch side top plating and hatch cover pad plating.);

③ Fillet weld between hatch side coaming top plating and hatch side coaming plating;

④ Fillet weld between hatch side coaming plating and upper deck plating;

⑤ Fillet weld between upper deck plating and inner hull/bulkheads;

⑥ Fillet weld between upper deck plating and longitudinal; and

⑦ Fillet weld between sheer strakes and upper deck plating.

Figure 4.8.1 Other Weld Areas

4.9 Concept examples of brittle crack arrest design

4.9.1 The followings are considered acceptable examples of measures that can be used on a brittle crack arrest-design to prevent brittle crack propagations. The detail design arrangements are to be submitted to CCS for their approval.

(1) Brittle crack arrest design for 4.8.1(b) (ii):

(a) Brittle crack arrest steel satisfying the performance specified in Chapter 3 of the Guidelines is to be used for the upper deck plating along the cargo hold region in a way suitable to arrest a brittle crack initiating from the coaming and propagating into the structure below.

(2) Brittle crack arrest design for 4.8.1(b) (i):

(b) Where the block to block butt welds of the hatch side coaming and those of the upper deck are shifted, this shift is to be greater than or equal to 300 mm. Brittle crack arrest steel is to be provided for the hatch side coaming plating.

(c) Where crack arrest holes are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, the fatigue strength of the lower end of the butt weld is to be assessed. Additional countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack

arrest steel in hatch side coaming plating.

(d) Where arrest insert plates of brittle crack arrest steel or weld metal inserts with high crack arrest toughness properties are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, additional countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack arrest steel in hatch side coaming plating.

(e) The application of enhanced NDT particularly time of flight diffraction (TOFD) or Phased Array Ultrasonic Testing (PAUT) technique using stricter defect acceptance in lieu of standard UT technique specified in 4.5 can be an alternative to (b), (c) and (d). Acceptance criteria of TOFD are ISO 15626 level 1, and acceptance criteria of PAUT are ISO 19285 level 2.

4.10 Selection of brittle crack arrest steels

4.10.1 The brittle crack arrest steels fitted in the upper deck region of container ships are to comply with relevant requirements for BCA1 and BCA2 steels in Chapter 3.

4.10.2 The brittle crack arrest steel property is to be selected for each individual structural member with thickness above 50 mm according to Table 4.10.2.

Brittle crack arrest steel requirement in function of structural members and thickness

Table 4.10.2

Structural Members plating*	Thickness (mm)	Brittle crack arrest steel requirement
Upper deck	$50 < t \leq 100$	Steel grade EH 36 or 40 with suffix BCA1
Hatch coaming side	$50 < t \leq 80$	Steel grade EH 40 or 47 with suffix BCA1
	$80 < t \leq 100$	Steel grade EH 40 or 47 with suffix BCA2
(*)Excluding their attached longitudinals		

4.10.3 When brittle crack arrest steels as specified in Table 4.10.2 are used, the weld joints between the hatch coaming side and the upper deck are to be partial penetration weld details approved by CCS. In the vicinity of ship block joints, alternative weld details may be used for the deck and hatch coaming side connection provided additional means for preventing the crack propagation are implemented and agreed by CCS in this connection area.

Annex 1 Approval of EH47 Steels

1 Scope

1.1 This Annex specifies requirements for works approval of higher strength hull structural EH47 steels.

1.2 Unless otherwise specified in this Annex, the approval of higher strength hull structural EH47 steels, including testing procedures, selection of testing products, position of specimen and testing items, is to satisfy relevant requirements for higher strength hull structural EH steels in CCS Guidelines for Inspection of Marine Rolled Steel Products (W01).

2 Approval tests

2.1 Extent of the approval tests

2.1.1 The approval of EH47 Steels does not cover the approval of lower strength level steels.

2.1.2 The products for testing are to represent the maximum thickness for approval. If the target chemical composition and manufacturing process change with the thickness, the maximum thickness for each specified chemical composition specification and each type of manufacturing process may be tested as required by CCS..

2.2 Type of tests

2.2.1 Brittle fracture initiation test

Deep notch test or Crack Tip Opening Displacement (CTOD) test is to be carried out. CTOD test is to be in accordance with the provisions of Section 8, Chapter 2, PART ONE of CCS Rules for Materials and Welding. The test temperature is -10℃. The average value is recommended not to be lower than 0.20 mm.

2.2.2 Weldability test

(1) Y-groove weld cracking test (Hydrogen crack test)

The test method is to be in accordance with recognized standards such as ISO 17642-2:2005.

(2) Brittle fracture initiation test

Deep notch test or CTOD test is to be carried out. CTOD test is to be in accordance with the provisions of Section 8, Chapter 2, PART ONE of CCS Rules for Materials and Welding. Crack tip is in the Grain-Coarsened Heat-Affected Zone (GCHAZ). The test temperature is -10℃, including the minimum and maximum heat input. The average value is recommended not to be lower than 0.15 mm.

2.2.3 Other tests

In addition to the requirement specified in 2.2.1 and 2.2.2 above, the approval tests required for higher strength hull structural EH steels in CCS Guidelines for Inspection of Marine Rolled Steel Products (W01) are to be carried out. Additional tests may be required when deemed necessary by CCS.

Annex 2 Approval of Brittle Crack Arrest Steels

1 Scope

1.1 This Annex specifies requirements for works approval of brittle crack arrest steels.

1.2 Unless otherwise specified in this Annex, the approval of brittle crack arrest steels is to be in accordance with provisions for EH36 or EH40 brittle crack arrest steels in CCS Guidelines for Inspection of Marine Rolled Steel Products (W01) and/or provisions for EH47 brittle crack arrest steels in Annex 1, satisfying requirements for EH36, EH40 and EH47 respectively.

2 Approval Application

2.1 Documents to be submitted

2.1.1 In addition to documents required in CCS Guidelines for Inspection of Marine Rolled Steel Products (W01), the following documents are to be submitted by the manufacturer:

(1) In-house test reports of the brittle crack arrest properties of the steels intended for approval;

(2) Approval test program for the brittle crack arrest properties;

(3) Production test procedure for the brittle crack arrest properties.

3 Approval tests

3.1 Extent of the approval tests

3.1.1 The extent of the test program is specified in 3.2, 3.3 and 3.4 of this Annex. For approval coverage range, see Table 3.1.1.

Approval Coverage Range Table 3.1.1

Test rating	Coverage rating
EH36BCA1	EH36BCA1
EH40BCA1	EH40BCA1, EH36BCA1①
EH40BCA2	EH40BCA2, EH40BCA1①, EH36BCA1①
EH47BCA1	EH47BCA1
EH47BCA2	EH47BCA2, EH47BCA1①

① The premise is similar composition design, same manufacturing process and same crack arrest mechanism.

3.1.2 The products for testing are to represent the maximum thickness for approval. If the target chemical composition and manufacturing process change with the thickness, the maximum thickness for each specified chemical composition specification and each type of manufacturing process may be tested as required by CCS.

3.1.3 The number of test samples and test specimens may be increased when deemed necessary, based on the in-house test reports of the brittle crack arrest properties of the steels intended for approval.

3.2 Type of tests

3.2.1 Brittle crack arrest tests are to be carried out in accordance with 3.3 of this Annex, in addition to the approval tests specified in CCS Guidelines for Inspection of Marine Rolled Steel Products (W01) (for EH40 or EH36 brittle crack arrest steels) and/or Annex 1 (for EH47 brittle crack arrest steels).

3.2.2 In the case of applying for addition of the specified brittle crack arrest properties for EH36,

EH40 and EH47 steels of which, manufacturing process has been approved by CCS (i.e. The aim analyses and method of manufacture are similar and the steelmaking process, deoxidation and fine grain practice, casting method and condition of supply are the same), brittle crack arrest tests, chemical analyses, tensile test and Charpy V-notch impact test may only be carried out in accordance with this Annex and CCS Guidelines for Inspection of Marine Rolled Steel Products (W01).

3.3 Test specimens and testing procedure of brittle crack arrest tests

3.3.1 The test specimens of the brittle crack arrest tests are to be taken with their longitudinal axis parallel to the final rolling direction of the test plates.

3.3.2 The loading direction of brittle crack tests is to be parallel to the final rolling direction of the test plates.

3.3.3 The thickness of the test specimens of the brittle crack arrest tests is to be the full thickness of the test plates.

3.3.4 If the initial specimen of the brittle crack arrest test does not meet the requirements of crack arrest property, another set of crack arrest specimen can be taken from the same steel plate, and the crack arrest test results of two groups of specimens are to be combined for evaluation.

3.3.5 The thickness of the test specimen is to be the maximum thickness of the steel plate requested for approval.

3.3.6 In the case where the brittle crack arrest properties are evaluated by K_{ca}, the brittle crack arrest test method is to be in accordance with Annex 3. In the case where the brittle crack arrest properties are evaluated by CAT, the test method is to be in accordance with Annex 4.

3.4 Other tests

3.4.1 Additional tests may be required when deemed necessary by CCS.

4 Results

4.1 Requirements for EH36 and EH40 steels in Chapter 3, PART ONE of CCS Rules for Materials and Welding, and those in Chapters 2 and 3 of the Guidelines are to be followed for the results.

4.2 Additionally, results of test items and the procedures are to comply with the approved test program. In the case where the brittle crack arrest properties are evaluated by K_{ca} or CAT, the manufacturer is to submit the brittle crack arrest test reports in accordance with Annex 3 for K_{ca} and Annex 4 for CAT.

5 Marks

5.1 Upon completion of approval, the suffix “BCA1” or “BCA2” (e.g. EH40-BCA1, EH47-BCA1, EH47-BCA2, etc.) is assigned to steels having relevant brittle crack arrest properties.

6 Renewal of certificate

6.1 The manufacturer is to submit actual manufacturing records of the approved brittle crack arrest steels within the term of validity of the works approval certificate.

Note: Chemical composition, mechanical properties, brittle crack arrest properties (e.g. brittle crack arrest test results or small-scale alternative test results) and nominal thickness are to be described in the form of histogram or statistics.

Annex 3 Test Method for Brittle Crack Arrest Toughness, K_{Ca}

1 Scope

1.1 ISO 20064:2019 provides a test method for the determination of brittle crack arrest toughness of steel by using wide plates with a temperature gradient.

1.2 This Annex specifies the test procedure for brittle crack arrest toughness (i.e. K_{ca}) of steel using fracture mechanics parameter and determination method of K_{ca} at a specific temperature which are specified in ISO 20064:2019. Additionally, this Annex specifies the evaluation method of K_{ca} of test plate. This Annex is applicable to hull structural steels with the thickness greater than or equal to 50 mm and not greater than 100 mm.

2 Test procedures

2.1 The test procedures including testing equipment, test specimens, test methods, determination of arrest toughness, reporting of test results, etc. are to be in accordance with ISO 20064:2019.

2.2 As a method for initiating a brittle crack, a secondary loading mechanism can be used in accordance with Annex D of ISO 20064: 2019.

2.3 The first sentence in Appendix B.2.4 of ISO 20064:2019 is revised to "{Kca /[K0 *exp(－c/TcaK)]} for each data point".

3 Determination of K_{ca} at a specific temperature

3.1 The method for conducting multiple tests to obtain K_{ca} value at a specific temperature is to be in accordance with Annex B of ISO 20064: 2019.

3.2 The straight-line approximation of Arrhenius plot for valid K_{ca} data by interpolation method are to comply with either the following (1) or (2):

(1) The evaluation temperature of K_{ca} (i.e. -10℃) is located between the upper and lower limits of the arrest temperature, with the K_{ca} corresponding to the evaluation temperature not lower than the required K_{ca} (e.g. 6000 N/mm$^{3/2}$ or 8000 N/mm$^{3/2}$), as shown in Figure A3-1.

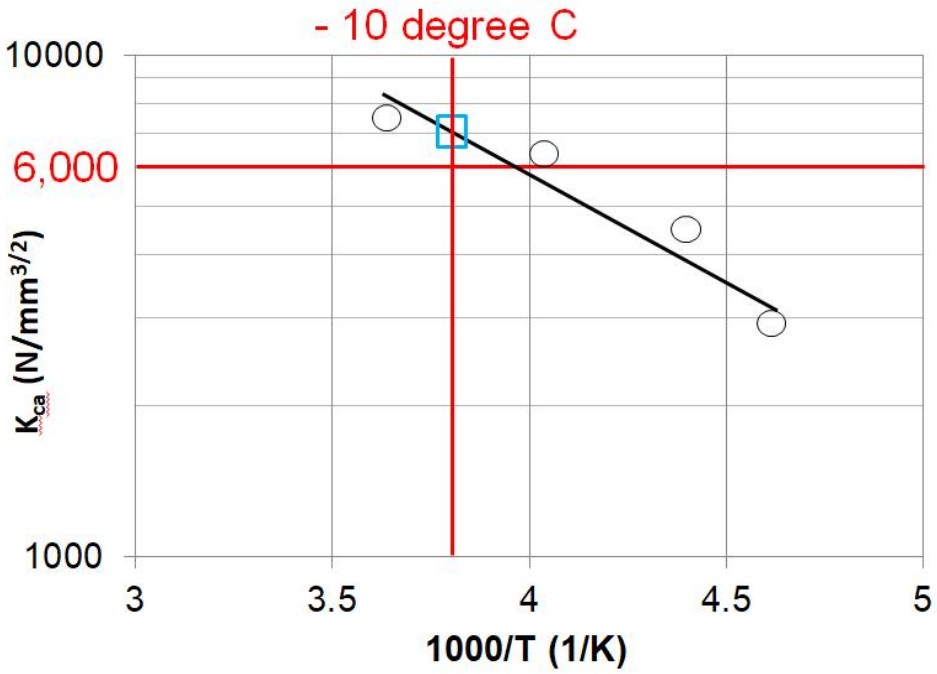


Figure A3-1 Example for evaluation of K_{ca} at - 10℃

(2) The temperature corresponding to the required K_{ca} (e.g. 6000 N/mm$^{3/2}$ or 8000 N/mm$^{3/2}$) is to be obtained by interpolation of the arrest temperature measured by test, and not higher than the evaluation temperature (i.e. -10℃), as shown in Figure A3-2.

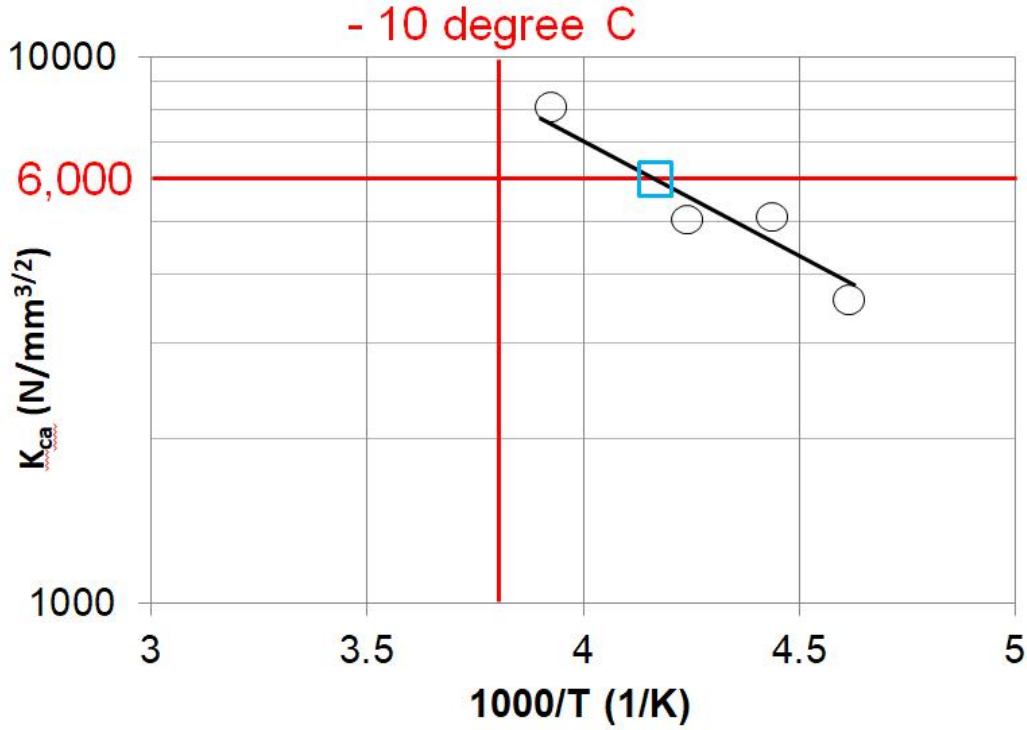


Figure A32 Example for evaluation of temperature corresponding to the required K_{ca}

If both of (1) and (2) above are not satisfied, conduct additional tests to satisfy this condition.

Annex 4 Outline of Requirements for Undertaking Isothermal Crack Arrest Temperature (CAT) Test

1 Scope of application

1.1 This Annex is to be applied according to the scope defined in the Guidelines.

1.2 This Annex specifies the requirements for test procedures and test conditions when using the isothermal crack arrest test to determine a valid test result under isothermal conditions and in order to establish the crack arrest temperature (CAT). This Annex is applicable to steels with thickness over 50 mm and not greater than 100 mm.

1.3 This method uses an isothermal temperature in the test specimen being evaluated. Unless otherwise specified in this Annex, the other test parameters are to be in accordance with ISO 20064:2019.

1.4 Table 3.2.2 of Chapter 3 of the Guidelines gives the relevant requirements for the brittle crack arrest property described by the crack arrest temperature (CAT).

1.5 The manufacturer is to submit the test procedure to CCS for review prior to testing.

2 Symbols and their significance

2.1 Table A4-1 supplements Table A1 in ISO 20064:2019 with specific symbols for the isothermal test.

Nomenclature supplementary to Table 1 in ISO 20064:2019 **Table A4-1**

Symbol	Unit	Significance
t	mm	Test specimen thickness
L	mm	Test specimen length
W	mm	Test specimen width
a_{MN}	mm	Machined notch length on specimen edge
L_{SG}	mm	Side groove length on side surface from the specimen edge. L_{SG} is defined as a groove length with constant depth except a curved section in depth at side groove end.
d_{SG}	mm	Side groove depth in section with constant depth
$L_{EB\text{ - }min}$	mm	Minimum length between specimen edge and electron beam re-melting zone front
$L_{EB\text{-}s1,\ -s2}$	mm	Length between specimen edge and electron beam re-melting zone front appeared on both specimen side surfaces
L_{LTG}	mm	Local temperature gradient zone length for brittle crack runway
a_{arrest}	mm	Arrested crack length
T_{target}	°C	Target test temperature
T_{test}	°C	Defined test temperature
T_{arrest}	°C	Target test temperature at which valid brittle crack arrest behaviour is observed
σ	N/mm^2	Applied test stress at cross section of $W * t$
SMYS	N/mm^2	Specified minimum yield strength of the tested steel grade to be approved
CAT	°C	Crack arrest temperature, the lowest temperature, T_{arrest}, at which running brittle crack is arrested

3 Testing equipment

3.1 The test equipment to be used is to be of the hydraulic type of sufficient capacity to provide a tensile load equivalent to ⅔ of SMYS of the steel grade to be approved.

3.2 The temperature control system is to be equipped to maintain the temperature in the specified region of the specimen within ±2°C from T_{target}.

3.3 Methods for initiating the brittle crack may be of drop weight type, air gun type or double tension tab plate type.

3.4 The detailed requirements for testing equipment are specified in ISO 20064:2019.

4 Test specimens

4.1 Impact type crack initiation

4.1.1 Test specimens are to be in accordance with ISO 20064:2019, unless otherwise specified in this Annex.

4.1.2 Specimen dimensions are shown in Figure A4-1. The test specimen width, W is to be 500 mm. The test specimen length, L is to be equal to or greater than 500 mm.

4.1.3 V-shape notch for brittle crack initiation is machined on the specimen edge of the impact side. The whole machined notch length is to be equal to 29 mm with a tolerance range of ±1 mm.

4.1.4 Requirements for side grooves are described in 4.4.

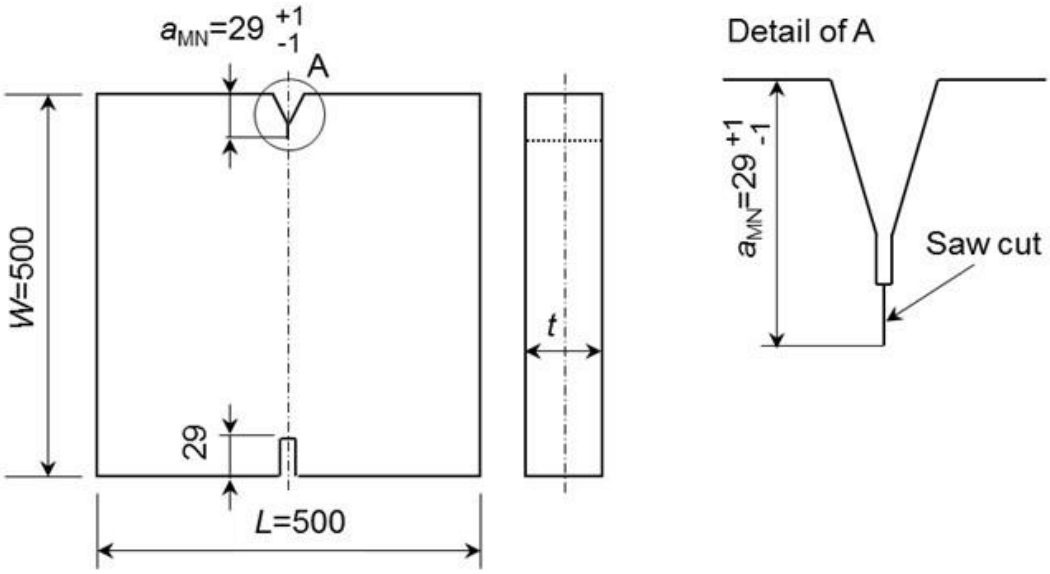


Figure A4-1 Test specimen dimensions for an impact type specimen

Note: Saw cut notch radius may be machined in the range 0.1 mmR and 1 mmR in order to control a brittle crack initiation at test.

4.2 Double tension type crack initiation

4.2.1 Reference is to be made to Appendix D in ISO 20064:2019 for the shape and sizes in secondary loading tab and secondary loading method for brittle crack initiation.

4.2.2 In a double tension type test, the secondary loading tab plate may be subject to further cooling to enhance an easy brittle crack initiation.

4.3 Embrittled zone setting

4.3.1 An embrittled zone is to be applied to ensure the initiation of a running brittle crack. Either Electron Beam Welding (EBW) or Local Temperature Gradient (LTG) may be adopted to facilitate the embrittled zone.

4.3.2 In EBW embrittlement, electron beam welding is applied along the expected initial crack propagation path, which is the centre line of the specimen in front of the machined V-notch.

4.3.3 The complete penetration through the specimen thickness is required along the embrittled zone. One side EBW penetration is preferable, but dual sides EB penetration may be also adopted when the EBW power is not enough to achieve the complete penetration by one side EBW.

4.3.4 The EBW embrittlement is recommended to be prepared before specimen contour machining.

4.3.5 In EBW embrittlement, zone is to be of an appropriate quality.

Note: EBW occasionally behaves in an un-stable manner at start and end points. EBW line is recommended to start from the embrittled zone tip side to the specimen edge with an increasing power control or go/return manner at start point to keep the stable EBW.

4.3.6 In LTG system, the specified local temperature gradient between machined notch tip and isothermal test region is regulated after isothermal temperature control. LTG temperature control is to be achieved just before brittle crack initiation, nevertheless the steady temperature gradient

through the thickness is to be ensured.

4.4 Side grooves

4.4.1 Side grooves on side surface can be machined along the embrittled zone to keep brittle crack propagation straight. Side grooves are to be machined in the specified cases as specified in this section.

4.4.2 In EBW embrittlement, side grooves are not necessarily mandatory. Use of EBW avoids the shear lips. However, when shear lips are evident on the fractured specimen, e.g. shear lips over 1 mm in thickness in either side then side grooves are to be machined to suppress the shear lips.

4.4.3 In LTG embrittlement, side grooves are mandatory. Side grooves with the same shape and size are to be machined on both side surfaces.

4.4.4 The length of side groove, L_{SG} is to be no shorter than the sum of the required embrittled zone length.

4.4.5 When side grooves would be introduced, the side groove depth, the tip radius and the open angle are not regulated, but are adequately selected in order to avoid any shear lips over 1 mm thickness in either side. An example of side groove dimensions is shown in Figure A4-2.

4.4.6 Side groove end is to be machined to make a groove depth gradually shallow with a curvature larger than or equal to groove depth, d_{SG}. Side groove length, L_{SG} is defined as a groove length with constant depth except a curved section in depth at side groove end.

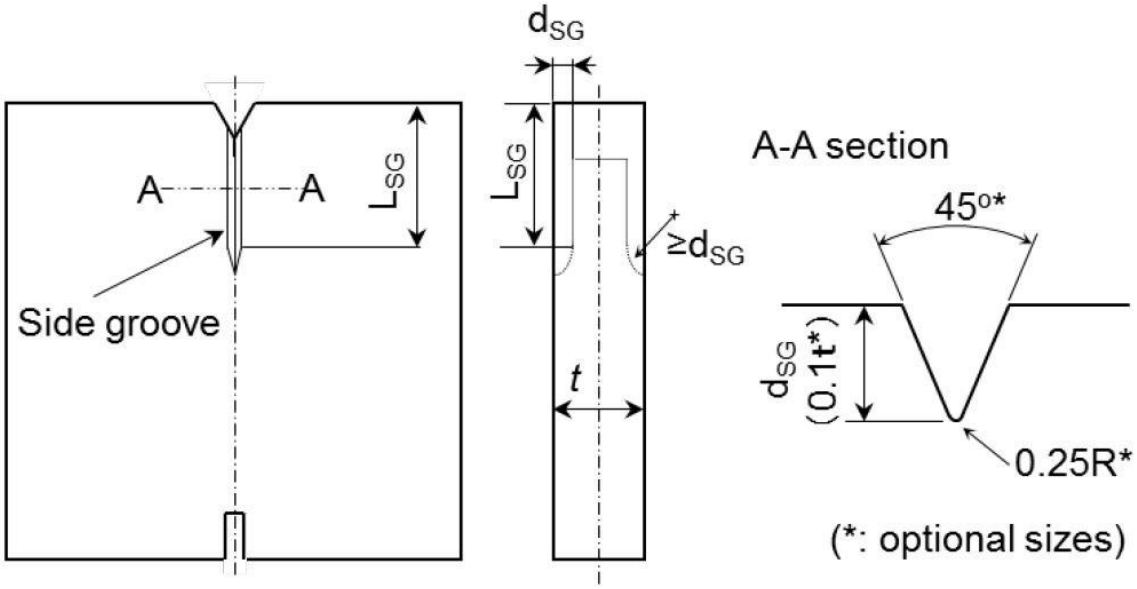


Figure A4-2 Side groove configuration and dimensions

4.5 Nominal length of embrittled zone

4.5.1 The length of embrittled zone is to be nominally at least 150 mm.

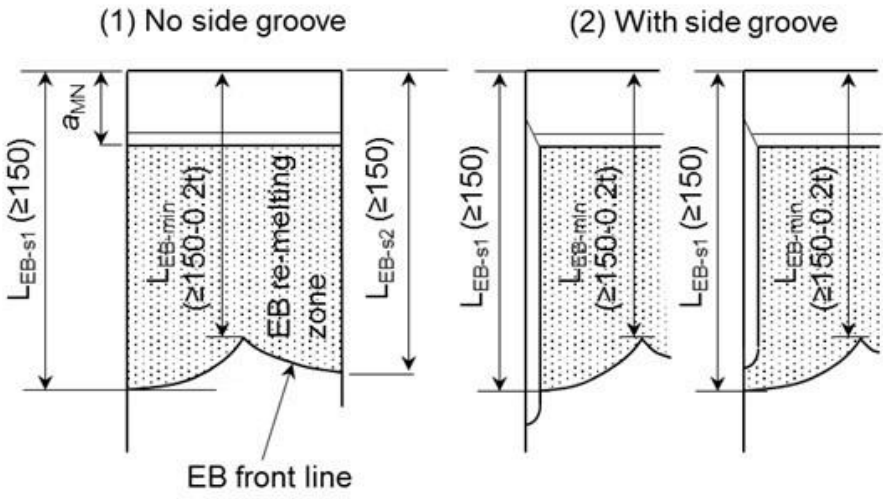


Figure A4-3 Definition of EBW length

4.5.2 EBW zone length is regulated by three measurements on the fracture surface after test as shown in Figure A4-3, L_{EB-min} between specimen edge and EBW front line, and L_{EB-s1} and L_{EB-s2}.

4.5.3 The minimum length between specimen edge and EBW front line, L_{EB-min} is to be no smaller than 150 mm. However, it can be acceptable even if L_{EB-min} is no smaller than 150mm-0.2t, where t is specimen thickness. When L_{EB-min} is smaller than 150 mm, a temperature safety margin is to be considered into T_{test} (See 8.1.2).

4.5.4 Another two are the lengths between specimen edge and EBW front appeared on both side surfaces, as denoted with L_{EB-s1} and L_{EB-s2}. Both of L_{EB-s1} and L_{EB-s2} are to be no smaller than 150 mm.

4.5.5 In LTG system, L_{LTG} is set as 150 mm.

4.6 Tab plate/pin chuck details and welding of test specimen to tab plates

4.6.1 The configuration and size of tab plates and pin chucks are to be referred to ISO 20064:2019. The welding distortion in the integrated specimen, which is welded with specimen, tab plates and pin chucks, is to be also within the requirement in ISO 20064:2019.

5 Test method

5.1 Preloading

5.1.1 Preloading at room temperature can be applied to avoid unexpected brittle crack initiation at test. The applied load value is to be no greater than the test stress. Preloading can be applied at higher temperature than ambient temperature when brittle crack initiation is expected at preloading process. However, the specimen is not to be subjected to temperature higher than 100℃.

5.2 Temperature measurement and control

5.2.1 Temperature control plan showing the number and position of thermocouples is to be in accordance with this section.

5.2.2 Thermocouples are to be attached to both sides of the test specimen at a maximum interval of 50 mm in the whole width and in the longitudinal direction at the test specimen centre position (0.5 W) within the range of ±100 mm from the centreline in the longitudinal direction, refer to Figure A4-4.

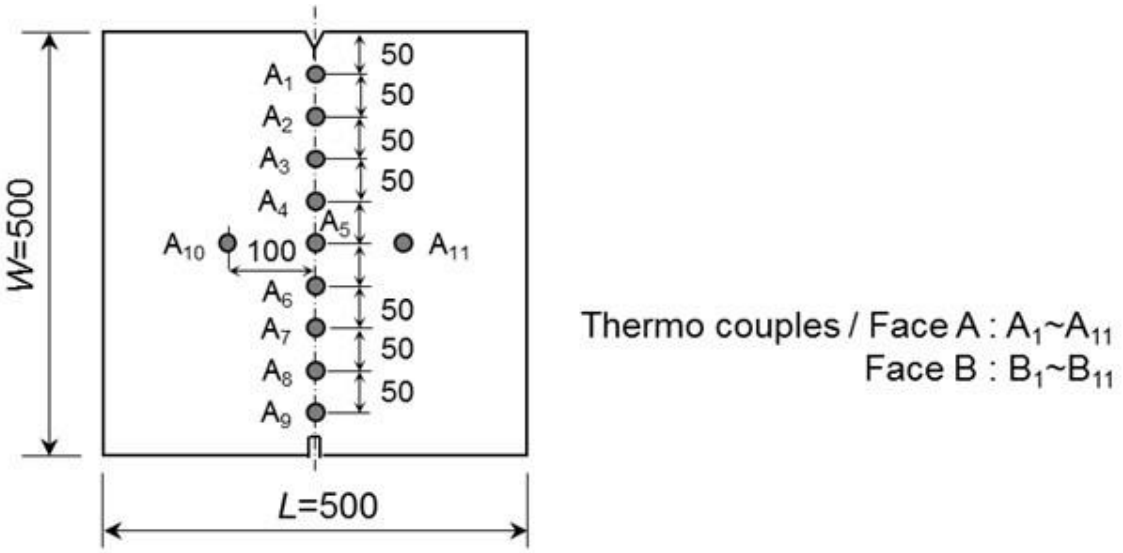


Figure A4-4 Locations of temperature measurement

5.2.3 For EBW embrittlement

5.2.3.1 The temperatures of the thermocouples across the range of 0.3W~0.7W in both width and longitudinal directions are to be controlled within ±2℃ of the target test temperature, T_{target}.

5.2.3.2 When all measured temperatures across the range of 0.3W~0.7W have reached T_{target}, steady temperature control is to be kept at least for 10 + 0.1*t[mm] minutes to ensure a uniform temperature distribution into mid-thickness prior to applying test load.

5.2.3.3 The machined notch tip can be locally cooled to easily initiate brittle crack. Nevertheless, the local cooling is not to disturb the steady temperature control across the range of 0.3W~0.7W.

5.2.4 For LTG embrittlement

5.2.4.1 In LTG system, in addition to the temperature measurements shown in Figure A4-4, the additional temperature measurement at the machine notch tip, A_0 and B_0 is required. Thermocouples positions within LTG zone are shown in Figure A4-5.

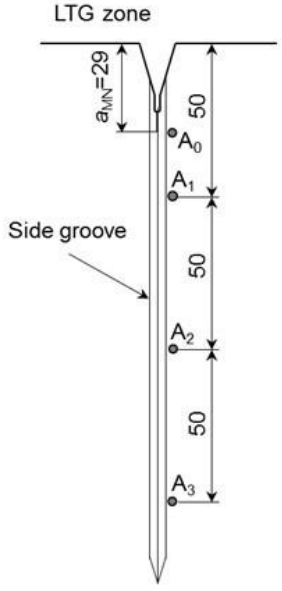


Figure A4-5 Detail of LTG zone and additional thermocouple A_0

5.2.4.2 The temperatures of the thermocouples across the range of 0.3W~0.7W in both width and longitudinal directions are to be controlled within ±2 ℃ of the target test temperature, T_{target}. However, the temperature measurement at 0.3W (location of A_3 and B_3) is to be in accordance with 5.2.4.6 below.

5.2.4.3 Once the all measured temperatures across the range of 0.3W~0.7W have reached T_{target}, steady temperature control is to be kept at least for 10+0.1*t[mm] minutes to ensure a uniform temperature distribution into mid-thickness, then the test load is applied.

5.2.4.4 LTG is controlled by local cooling around the machined notch tip. LTG profile is to be recorded by the temperature measurements from A_0 to A_3 shown in Figure A4-6.

5.2.4.5 LTG zone is established by temperature gradients in three zones, Zone I, Zone II and Zone III. The acceptable range for each temperature gradient is listed Table A4-2.

5.2.4.6 Temperature measurements at A_2, B_2 and A_3, B_3 are to be satisfied the following requirements:

T at A_3, T at $B_3 < T_{target} - 2$℃

T at $A_2 < T$ at $A_3 - 5$℃

T at $B_2 < T$ at $B_3 - 5$℃

5.2.4.7 No requirements for T at A_0 and T at A_1 temperatures when T at A_3 and T at A_2 satisfy the requirements above. Face B is the same.

5.2.4.8 The temperatures from A_0, B_0 to A_3, B_3 are to be decided at test planning stage refer to Table A4-2 which gives the recommended temperature gradients in three zones, Zone I, Zone II and Zone III in LTG zone.

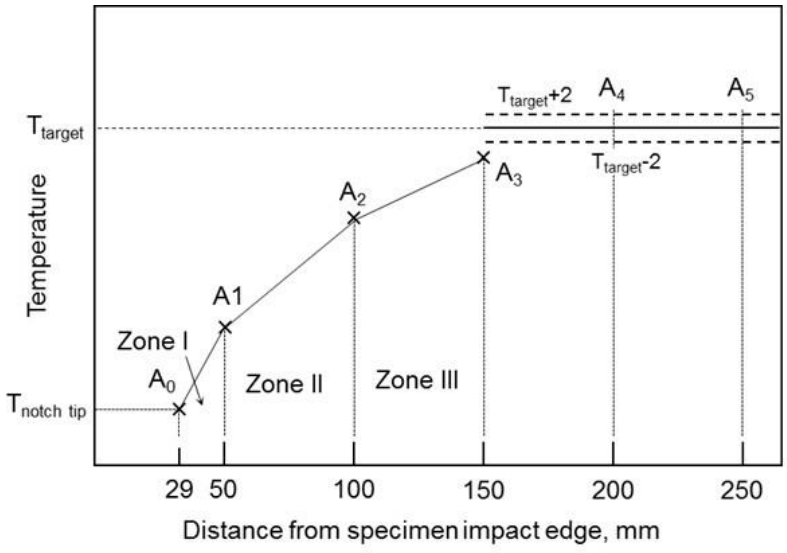


Figure A4-6 Schematic temperature gradient profile in LTG zone

Acceptable LTG range **Table A4-2**

Zone	Location from edge	Acceptable range of temperature gradient
Zone I	29 mm – 50 mm	2.00 ˚C/mm – 2.30 ˚C/mm
Zone II	50 mm – 100 mm	0.25 ˚C/mm – 0.60 ˚C/mm
Zone III[1)]	100 mm – 150 mm	0.10 ˚C/mm – 0.20 ˚C/mm

Note 1: The Zone III arrangement is mandatory

5.2.4.9 The temperature profile in LTG zone mentioned above is to be ensured after holding time at least for 10+0.1*t[mm] minutes to ensure a uniform temperature distribution into mid-thickness before brittle crack initiation.

5.2.4.10 The acceptance of LTG in the test is to be decided from Table A4-2 based on the measured temperatures from A_0 to A_3.

5.2.5 For double tension type crack initiation specimen

5.2.5.1 Temperature control and holding time at steady state are to be the same as the case of EBW embrittlement specified in 5.2.3 or the case of LTG embrittlement specified in 5.2.4.

5.3 Loading and brittle crack initiation

5.3.1 Prior to testing, a target test temperature (T_{target}) is to be selected.

5.3.2 Test procedures are to be in accordance with ISO 20064:2019 except that the applied stress is to be ⅔ of SMYS of the steel grade tested.

5.3.3 The test load is to be held at the test target load or higher for a minimum of 30 seconds prior to crack initiation.

5.3.4 Brittle crack can be initiated by impact or secondary tab plate tension after all of the temperature measurements and the applied force are recorded.

6 Measurements after test and test validation judgement

6.1 Brittle crack initiation and validation

6.1.1 If brittle crack spontaneously initiates before the test force is achieved or the specified hold time at the test force is not achieved, the test is to be invalid.

6.1.2 If brittle crack spontaneously initiates without impact or secondary tab tension but after the specified time at the test force is achieved, the test is considered as a valid initiation. The following validation judgments of crack path and fracture appearance are to be examined.

6.2 Crack path examination and validation

6.2.1 When brittle crack path in embrittled zone deviates from EBW line or side groove in LTG system due to crack deflection and/or crack branching, the test is to be considered as invalid.

6.2.2 All of the crack path from embrittled zone end is to be within the range shown in Figure A4-7. If not, the test is to be considered as invalid.

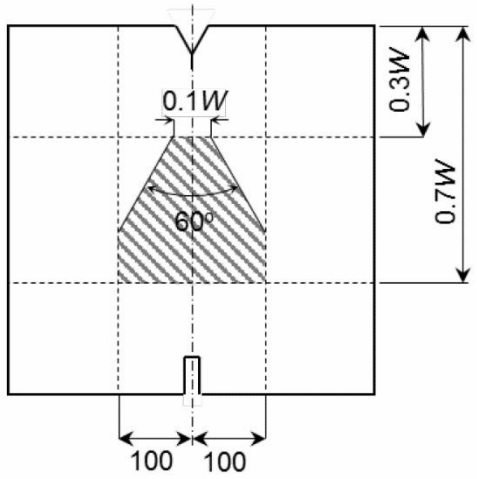


Figure A4-7 Allowable range of main crack propagation path

6.3 Fracture surface examination, crack length measurement and their validation

6.3.1 Fracture surface is to be observed and examined. The crack "initiation" and "propagation" are to be checked for validity and judgements recorded. The crack "arrest" positions are to be measured and recorded.

6.3.2 When crack initiation trigger point is clearly detected at side groove root, other than the V-notch tip, the test is to be invalid.

6.3.3 In EBW embrittlement setting, EBW zone length is quantified by three measurements of $L_{EB\text{-}s1}$, $L_{EB\text{-}s2}$ and $L_{EB\text{-}min}$, which are defined in 4.5. When either or both of $L_{EB\text{-}s1}$ and $L_{EB\text{-}s2}$ are smaller than 150 mm, the test is to be invalid. When $L_{EB\text{-}min}$ is smaller than 150mm-0.2t, the test is to be invalid.

6.3.4 When the shear lip with thickness over 1mm in either side near side surfaces of embrittled zone are visibly observed independent of the specimens with or without side grooves, the test is to be invalid.

6.3.5 In EBW embrittlement setting, the penetration of brittle crack beyond the EBW front line is to be visually examined. When any brittle fracture appearance area continued from the EB front line is not detected, the test is to be invalid.

6.3.6 The weld defects in EBW embrittled zone are to be visually examined. If detected, it is to be quantified. A projecting length of defect on the thickness line through EB weld region along brittle crack path is to be measured, and the total occupation ratio of the projected defect part to the total thickness is defined as defect line fraction (See Figure A4-8). When the defects line fraction is larger than 10 %, the test is to be invalid.

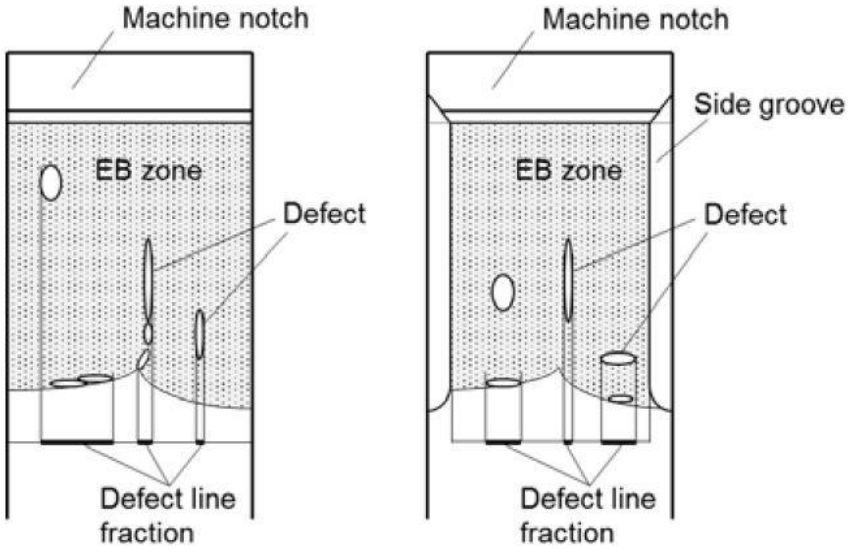


Figure A4-8 Counting procedure of defect line fraction

6.3.7 In EBW embrittlement by dual sides' penetration, a gap on embrittled zone fracture surface which is induced by miss meeting of dual fusion lines is visibly detected at an overlapped line of dual side penetration, the test is to be invalid.

7 Judgement of "arrest" or "propagate"

7.1 The final test judgment of "arrest", "propagate" or "invalid" is decided by the following requirements of 7.2 through 7.6.

7.2 If initiated brittle crack is arrested and the tested specimen is not broken into two pieces, the fracture surfaces are to be exposed with the procedures specified in ISO 20064:2019.

7.3 When the specimen was not broken into two pieces during testing, the arrested crack length, a_{arrest} is to be measured on the fractured surfaces. The length from the specimen edge of impact side to the arrested crack tip (the longest position) is defined as a_{arrest}.

7.4 For LTG and EBW, a_{arrest} is to be greater than L_{LTG} and $L_{EB\text{-}s1}$, $L_{EB\text{-}s2}$ *or* $L_{EB\text{-}min}$. If not, the test is to be considered as invalid.

7.5 Even when the specimen was broken into two pieces during testing, it can be considered as "arrest" when brittle crack re-initiation is clearly evident. Even in the fracture surface all occupied by brittle fracture, when a part of brittle crack surface from embrittled zone is continuously surrounded by thin ductile tear line, the test can be judged as re-initiation behaviour. If so, the maximum crack length of the part surrounded tear line can be measured as a_{arrest}. If re-initiation is not visibly evident, the test is judged as "propagate".

7.6 The test is judged as "arrest" when the value of a_{arrest} is no greater than $0.7W$. If not, the test is judged as "propagate".

8 T_{test}, T_{arrest} and CAT determination

8.1 T_{test} determination

8.1.1 It is to be ensured on the thermocouple measured record that all temperature measurements across the range of $0.3W$~$0.7W$ in both width and longitudinal direction are in the range of T_{target} ±2°C at brittle crack initiation. If not, the test is to be invalid. However, the temperature measurement at $0.3W$ (location of A_3 and B_3) in LTG system is to be exempted from this requirement.

8.1.2 If $L_{EB\text{-}min}$ in EBW embrittlement is no smaller than 150 mm, T_{test} can be defined to equal with T_{target}. If not, T_{test} is to be equaled with T_{target} + 5˚C.

8.1.3 In LTG embrittlement, T_{test} can be equaled with T_{target}.

8.1.4 The final arrest judgment at T_{test} is concluded by at least two tests at the same test condition which are judged as "arrest".

8.2 T_{arrest} determination

8.2.1 When at least repeated two "arrest" tests appear at the same T_{target}, brittle crack arrest behaviour at T_{target} will be decided ($T_{arrest} = T_{target}$).When a "propagate" test result is included in the multiple test results at the same T_{target}, the T_{target} cannot to be decided as T_{arrest}.

8.3 CAT determination

8.3.1 When CAT is determined, one "propagate" test is needed in addition to two "arrest" tests. The target test temperature, T_{target} for "propagate" test is recommended to select 5°C lower than T_{arrest}. The minimum temperature of T_{arrest} is determined as CAT.

8.3.2 With only the "arrest" tests, without "propagation" test, it is decided only that CAT is lower than T_{test} in the two "arrest" tests, i.e. not deterministic CAT.

9 Reporting

9.1 The following items are to be reported:

(i) Test material: grade and thickness;

(ii) Test machine capacity;

(iii) Test specimen dimensions: thickness t; width W and length L; notch details and length a_{MN},

side groove details if machined;
(iv) Embrittled zone type: EBW or LTG embrittlement;
(v) Integrated specimen dimensions: tab plate thickness, tab plate width, integrated specimen unit length including the tab plates, and distance between the loading pins, angular distortion and linear misalignment;
(vi) Brittle crack trigger information: impact type or double tension. If impact type, drop weight type or air gun type, and applied impact energy;
(vii) Test conditions; Applied load, preload stress, test stress;
- Judgements for preload stress limit, hold time requirement under steady test stress.
(viii) Test temperature: complete temperature records with thermocouple positions for measured temperatures (figure and/or table) and target test temperature;
- Judgements for temperature scatter limit in isothermal region.
- Judgement for local temperature gradient requirements and holding time requirement after steady local temperature gradient before brittle crack trigger, if LTG system is used.
(ix) Crack path and fracture surface: tested specimen photos showing fracture surfaces on both sides and crack path side view; Mark at “embrittled zone tip” and “arrest” positions;
- Judgment for crack path requirement.
- Judgment for cleavage trigger location (whether side groove edge or V-notch edge).
(x) Embrittled zone information:
When EBW is used: $L_{EB\text{-}s1}$, $L_{EB\text{-}s2}$ and $L_{EB\text{-}min}$
- Judgement for shear lip thickness requirement
- Judgment whether brittle fracture appearance area continues from the EBW front line
- Judgement for EBW defects requirement
- Judgement for EBW lengths, $L_{EB\text{-}s1}$, $L_{EB\text{-}s2}$ and $L_{EB\text{-}min}$ requirements
When LTG is used: L_{LTG}
- Judgment for shear lip thickness requirement
Test results:
When the specimen did not break into two pieces after brittle crack trigger, arrested crack length a_{arrest}
When the specimen broke into two pieces after brittle crack trigger,
- judgement whether brittle crack re-initiation or not.
If so, arrested crack length a_{arrest}:
- Judgement for a_{arrest} in the valid range ($0.3W < a_{arrest} \leqslant 0.7W$)
- Final judgement either “arrest”, “propagate” or “invalid”
(xi) Dynamic measurement results: History of crack propagation velocity, and strain change at pin chucks, if needed.

10 Use of test for material qualification testing

10.1 Where required, the method can also be used for determining the lowest temperature at which a steel can arrest a running brittle crack (the determined CAT) as the material property characteristic in accordance with 8.3.

Annex 5 Approval Scheme of

Small-scale Test Methods for Brittle Crack Arrest Steels

1 Scope

1.1 This Annex specifies the approval scheme of small-scale test methods which are used for product inspection (batch release testing) of brittle crack arrest steel specified in Table 3.2.2 of the Guidelines.

1.2 Unless otherwise specified in this Annex, the requirements of Annex 1 and/or Annex 2 are to be followed.

2 Approval application

2.1 The manufacturer is to submit following documents to CCS:

(1) Application for approval of small-scale test procedure specification;

(2) Small-scale test procedure specification including the following items at least:

① Steel grades, thickness range, deoxidation practice and heat treatment, etc.;

② Types and methods of small-scale tests;

③ Sampling positions in plate thickness direction and final rolling direction of test specimens;

④ Size and dimension of test specimens;

⑤ Number of test specimens;

⑥ Test conditions, such as test temperature;

⑦ Acceptance criteria;

⑦ Example of format of test report;

⑨ Example of product inspection certificate including small-scale test results;

⑩ Handling of the products when small-scale test results do not satisfy the criterion.

(3) Mechanism of achieving the brittle crack arrest properties of brittle crack arrest steels;

(4) Technical background for enabling the evaluation of brittle crack arrest properties by small-scale test methods considering the mechanism specified in above (3);

(5) Procedure of the evaluation for the brittle crack arrest properties of brittle crack arrest steels by small-scale test results;

(6) Data records which validate the correlation between small-scale test results and the large brittle crack arrest test results of brittle crack arrest steels whose number can satisfy the requirement for minimum data number given in 3.3 of this Annex;

(7) Proposed test plan for approval.

2.2 Small-scale test procedure specification is to be prepared in accordance with 3 of this Annex.

2.3 Where the manufacturer proposes to change any part of the approved small-scale test procedure specification, then the manufacturer is to submit to CCS the documents which can cover all items specified in 2.1 of this Annex.

2.4 The documents confirming the reason for the change are to be submitted to identify the impact of those changes on the existing procedure, and the proposed actions to address any such impacts.

3 Establishment of procedure specification for small-scale testing

3.1 General requirements

3.1.1 Small-scale test methods are to be determined based on the manufacturer's own technical philosophy with regard to achieving the brittle crack arrest properties of brittle crack arrest steels. Furthermore, description of an appropriate correlation between large scale brittle crack arrest properties and small-scale test results is to be required, and the acceptance criteria of the small-scale test are to be determined, based on the followings:

(1) Mechanism of achieving the suitable brittle crack arrest properties;

(2) Sampling position and direction;

(3) Sampling frequency;

(4) Small-scale test methodology;

(5) Demonstrated correlation between brittle crack arrest test results and small-scale test results;

(6) Derivation of small scale testing acceptance criteria based on the statistical analysis.

3.1.2 The manufacturer is to prepare the small-scale test procedure specification in accordance with 3.2 to 3.5 of this Annex.

3.2 Types and methods of testing

3.2.1 Types, methods, dimension and positions as well as direction of test specimens, etc. of small-scale tests are to be specified by the manufacturer, and approved in accordance with the Guidelines.

3.2.2 In general, the test method is to reproduce the crack initiation, propagation and arrest feature by such as the following test method:

① Combination of test methods, e.g. NRL drop weight test and V-notch Charpy impact test;

② One test method, e.g. press-notch Charpy impact test or side-section drop weight test.

3.2.3 In general, brittle crack arrest properties of brittle crack arrest steels are to be predicted using a regression equation on the relationship between small-scale test result (e.g. transition temperature obtained by small-scale tests) and large-scale brittle crack arrest test result (e.g. K_{ca} or temperature corresponding to the specific brittle crack arrest properties). Other approaches can be used subject to the approval of CCS.

Note: Table A5-1, Table A5-2 and Table A5-3 give the examples of small-scale test methods.

3.2.4 For determination of test methods, the manufacturer is to confirm the applicability of these test methods to their brittle crack arrest steels theoretically taking into account the methodology of test methods, their own mechanism of achieving the brittle crack arrest properties, and sampling positions of test specimens (See 3.1.1 of this Annex). Then, the manufacturer is to also submit the technical background for determination of small-scale test methods to CCS as given in 2.1 of this Annex.

3.3 Testing data

3.3.1 Selection of test plates

3.3.1.1 Brittle crack arrest tests and small-scale tests are to be conducted for each material grade (including all suffixes) of brittle crack arrest steels in accordance with 3.3 of this Annex.

3.3.1.2 Brittle crack arrest tests and small-scale tests are to be carried out on at least 12 test plates, in accordance with 3.3.1.3, and an appropriate decrease in the number of test plates may be accepted with the agreement of CCS, by which these test results can reliably estimate brittle crack arrest properties of brittle crack arrest steels.

Note: "One test plate" means "the rolled product from a single slab or ingot if this is rolled directly into plates".

3.3.1.3 In order to ensure appropriate correlation between small-scale test results and brittle crack arrest properties with various manufacturing conditions of steel plates, the steel plates are to be representative for each combination of thickness range and heat sample to include:

(1) The intended maximum and minimum plate thickness;

(2) Different heats are to be chosen for each thickness.

Furthermore, the above test plates are to include a fixed number of steel plate(s) whose brittle crack arrest properties (i.e. brittle crack arrest test results) do not comply with the requirements specified in Table 3.2.2 of the Guidelines. Such a number is to be at least one, but not exceeding one quarter of all test plates. Manufacturing process of these test plates can be different (or intentionally altered from the approved manufacturing process) from that of the brittle crack arrest steels to which the small-scale test method is applied. It is recommended that the strength grade of these test plates (non-compliant with the relevant requirements of brittle crack arrest properties) are similar to that of the brittle crack arrest steels.

Where the manufacturer has requested approval for only a single thickness, the thickness of test plates can be only a single thickness. In this case, at least four steel plates for each combination of thickness (single thickness) and heats (three different heats) are to be used, and the applicable thickness of the small-scale test is only that single thickness condition.

3.3.1.4 Brittle crack arrest steels used for the approval test of manufacturing process of these steels (and its approval test results) can also be used as the test plates specified in 3.3.1.3 of this Annex.

3.3.1.5 Brittle crack arrest test specimens and small-scale test specimens are to be taken from the same test plate.

3.3.1.6 A decrease of the total of the indicated number of test plates may be accepted by CCS in the following (1) or (2) cases:

(1) When the manufacturer applies a small-scale test procedure specification to multiple material grades, and the manufacturing process and mechanism to ensure the brittle crack arrest properties of these different material grades are the same;

(2) When a small-scale test procedure specification is already approved by CCS for one or some material grades, and the manufacturer applies similar small-scale test procedure specification to the other material grade(s), and the manufacturing process and mechanism to ensure the brittle crack arrest properties of these different material grades are same.

3.3.2 Brittle crack arrest tests

3.3.2.1 Brittle crack arrest tests are to be carried out for each test plate in accordance with Annex 2.

3.3.2.2 Where brittle crack arrest tests are carried out for evaluation of K_{ca}, K_{ca} at a specific temperature is to be obtained in accordance with Annex 3.

3.3.2.3 Where brittle crack arrest tests are carried out for evaluation of CAT, deterministic (actual) CAT is to be obtained in accordance with Annex 4.

3.3.3 Small-scale tests

3.3.3.1 Small-scale tests are to be carried out in accordance with small-scale test procedure specification to be approved for each test plate.

3.3.3.2 In general, the test specimens of small-scale tests are to be taken with their longitudinal axis parallel to the final rolling direction of the test plates.

3.3.3.3 The test specimens of small-scale tests are to be taken from the specified positions in plate thickness direction of the test plates, as given in 3.2.3 of this Annex.

3.4 Validation of correlation

3.4.1 A regression equation on the relationship between brittle crack arrest property obtained from brittle crack arrest test and single or multiple small-scale test results is to be established. For brittle crack arrest properties, a specific temperature (e.g. $T_{Kca6000}$ in BCA1, $T_{Kca8000}$ in BCA2 or CAT) or the K_{ca} value at -10℃ may be used.

3.4.2 The validity of the regression equation is to be examined to predict brittle crack arrest properties with enough accuracy. The correlation in brittle crack arrest properties between the calculated values from small scale tests and the brittle crack arrest test results is to be assured by using the value of twice the standard deviation (2σ). When using temperature for brittle crack arrest property, 2σ is not to be greater than 20℃. In other cases (e.g. K_{ca} value at -10℃), an upper limit of 2σ is to be established with the agreement of CCS.

Note: Calculation procedure of the standard deviation (σ) is given as follows:

$$\sigma = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(y_i - x_i)^2}$$

n: number of test plates;

y_i: brittle crack arrest property obtained from brittle crack arrest test for one test plate;

x_i: brittle crack arrest property estimated from small-scale tests for one test plate.

3.5 Acceptance criterion

3.5.1 Acceptance criterion of brittle crack arrest steels by the small-scale tests is to be proposed by the manufacturer based on the regression equation which is assured in the correlation with brittle crack arrest properties in 3.4 of this Annex. The criterion is to be determined so that regression equation can predict brittle crack arrest properties on safety side, considering the scatter of brittle crack arrest properties from the predicted value by the regression equation.

3.5.2 Unless otherwise agreed by CCS, an acceptance criterion of small-scale tests is to be determined by following procedures:

(1) For correlation by means of temperature

① The required temperature (see Figure 3.5.2(a)) is obtained by subtracting 2σ (℃) from the brittle crack arrest steel specification in Table 3.2.2 of the Guidelines, that is -10-2σ (℃), where 2σ is given in 3.4.2 of this Annex.

$T_{Kca6000}$ and $T_{Kca8000}$ in Figure 3.5.2(a) are the temperatures at which the K_{ca} value of steel plates equals 6000N/mm$^{3/2}$ and 8000N/mm$^{3/2}$, respectively.

② The temperature predicted from the small-scale test results through the regression equation is to be no higher than the value of -10-2σ(℃).

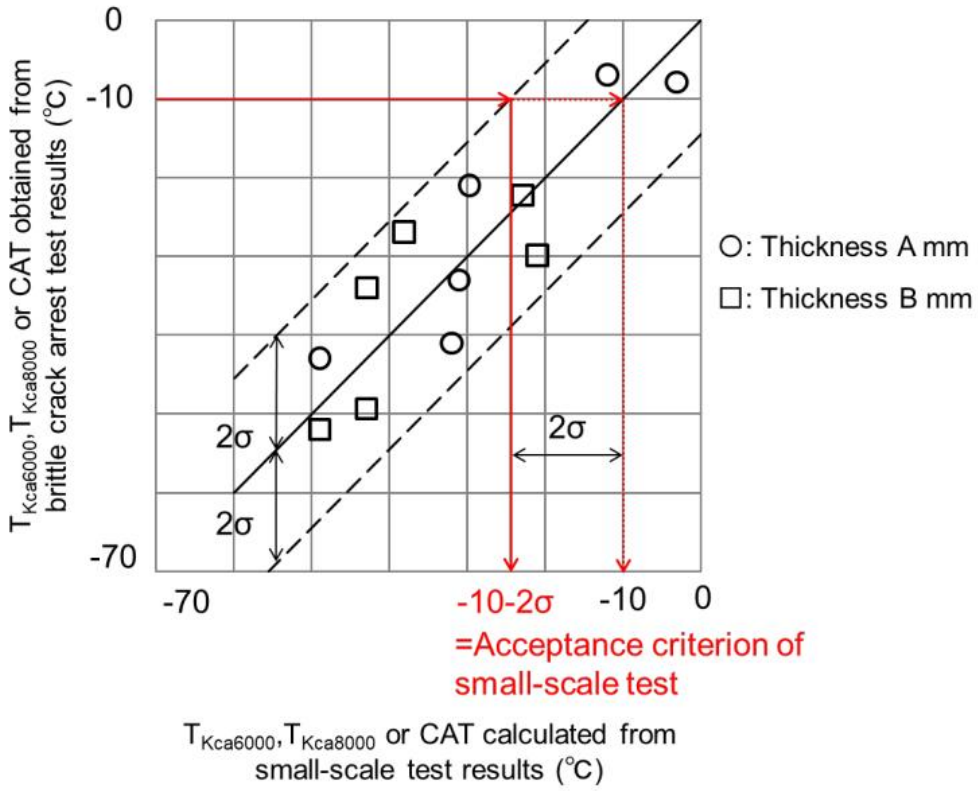


Figure 3.5.2(a) Example for determination of acceptance criterion of small-scale test for correlation by means of temperature

(Note: This is only a schematic and may not represent the actual data obtained)

(2) For correlation by means of brittle crack arrest toughness (K_{ca}):

① The required K_{ca} (see Figure 3.5.2(b)) is obtained by adding 2σ ($N/mm^{3/2}$) to the brittle crack arrest steel specification in Table 3.2.2 of the Guidelines, that is either 6000+2σ($N/mm^{3/2}$) in BCA1 or 8000+2σ($N/mm^{3/2}$) in BCA2, where 2 σ is given in 3.4.2 of this Annex.

② The K_{ca} value predicted from the small-scale test results through the regression equation is to be no smaller than the value of 6000+2σ($N/mm^{3/2}$) for BCA1, or 8000+2σ($N/mm^{3/2}$) for BCA2.

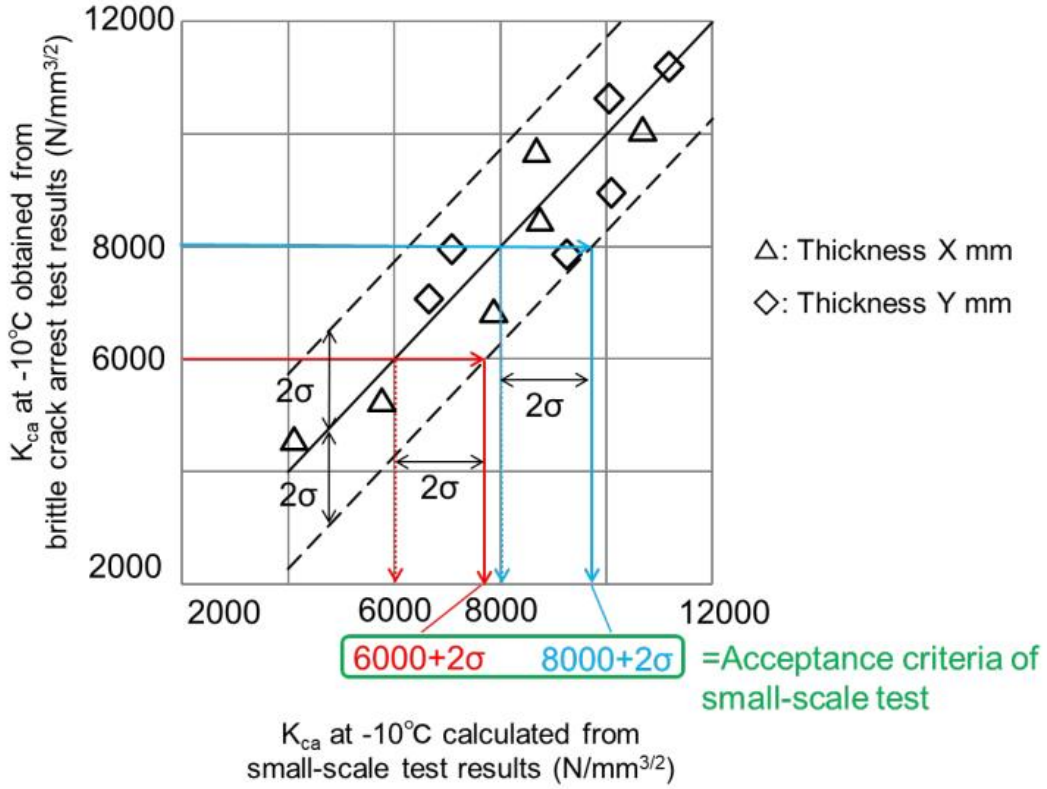


Figure 3.5.2(b) Example for determination of acceptance criteria of small-scale test for correlation by means of brittle crack arrest toughness (K_{ca})
(Note: This is only a schematic and may not represent the actual data obtained)

4 Approval Tests

4.1 General requirements

4.1.1 In order to confirm the validity of the submitted technical documents specified in 2.1 of this Annex, approval tests are to be carried out.

4.1.2 Approval test plan is to be approved by CCS prior to testing.

4.1.3 Considering the contents of the submitted technical documents specified in 2.1 of this Annex, CCS may require additional tests in the following cases:

(1) When CCS determines that the number of brittle crack arrest tests or small-scale tests is too few to adequately confirm the validity of the acceptance criterion of small-scale tests;

(2) When CCS determines that the testing data obtained for setting the acceptance criterion of small-scale tests varies too widely (See 3.4.2 of this Annex);

(3) When CCS determines that the validity of brittle crack arrest test results or small-scale test results for setting the acceptance criterion of small-scale tests is insufficient, or has some flaws during tests and/or for test results (See 3.3.2 and 3.3.3 of this Annex); and

(4) Others as deemed necessary by CCS.

4.2 Extent of the approval tests

4.2.1 Extent of the approval tests is to be in accordance with 2.1 of Annex 1 and 3.1 of Annex 2.

4.3 Type of tests4.3.1 Brittle crack arrest tests

4.3.1.1 Brittle crack arrest tests are to be carried out in accordance with 3.3 of Annex 2.

4.3.1.2 Where brittle crack arrest tests are carried out for evaluation of K_{ca}, K_{ca} at a specific temperature ($T_{Kca6000}$ or $T_{Kca8000}$) is to be obtained in accordance with 3 of Annex 3.

4.3.1.3 Where brittle crack arrest tests are carried out for evaluation of CAT, deterministic CAT is to be obtained in accordance with Annex 4.

4.3.2 Small-scale tests

4.3.2.1 Small-scale tests are to be carried out in accordance with 3.3 of this Annex.

5 Results

5.1 Results of test items and the procedures are to comply with the test program approved by CCS.

5.2 For the brittle crack arrest test results, the manufacturer is to submit to CCS the brittle crack arrest test reports in accordance with Annex 3 for K_{ca} and Annex 4 for CAT.

5.3 For small-scale test results, the manufacturer is to submit to CCS the small-scale test reports in accordance with the example of format of test reports submitted as specified in 2.1b) of this Annex.

6 Approval

6.1 Upon satisfactory completion of the survey and tests, and satisfactory confirmation of the submitted technical documents, the approval for small-scale test procedure specification is granted by CCS.

Example of small-scale test method using NRL drop weight test and V-notch Charpy impact test (Informative) **Table A5-1**

Test type	NRL drop weight test and V-notch Charpy impact test
Standard	ASTM E208:2020 and ISO 148-1:2016
Sampling positions of test specimens	NRL drop weight test: at surface V-notch charpy impact test: 1/4 of thickness
Length direction of test specimen	Parallel to the final rolling direction of test plate
Regression equation:	$T_{Kca} = \alpha \cdot (NDTT + 10) + \beta \cdot vTrs + 153 (t - 5)^{1/13} - 170.5$ T_{Kca}: Temperature at K_{ca} of 6,000N/mm$^{3/2}$ or K_{ca} of 8,000N/mm$^{3/2}$, (℃) $NDTT$: Nil-ductility transition temperature (℃) $_vT_{rs}$: Transition temperature of the absorbed energy (℃) t: thickness α, β (1): constant
Notes:	(1) α and β are determined by comparing small-scale test results with brittle crack arrest test results.

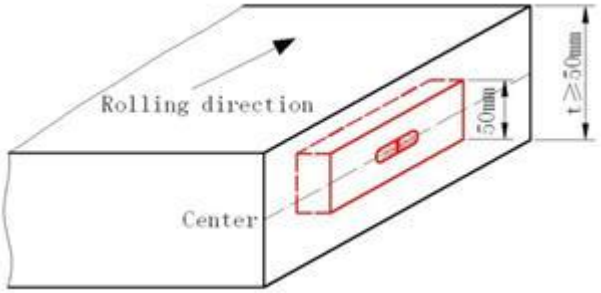
Example of small-scale test method using pressed-notch Charpy impact test (Informative)

Table A5-2

Test type	Pressed-notch Charpy impact test
Standard	Dimension, shape, introducing method of notch: manufacturer's proposal Others: ISO148-1:2016
Sampling position of test specimens	1/2 of thickness
Length direction of test specimen	Parallel to the final rolling direction of test plate
Regression equation	$T_{Kca} = \alpha\, {}_pT_{E\gamma J} + \beta$ T_{Kca}: Temperature at K_{ca} of 6,000N/mm$^{3/2}$ or K_{ca} of 8,000N/mm$^{3/2}$, (℃) ${}_pT_{E\gamma J}$: Test temperature at absorbed energy of γ (J), (℃) α and β: Constant γ: Absorbed energy at brittle fracture surface ratio of δ (%),(J)
Notes	(1) α, β, γ and δ are determined by comparing small-scale test results with brittle crack arrest test results.

Example of small-scale test method using side-section drop weight test (Informative)

Table A5-3

Test type	Side-section drop weight test
Standard	Dimension: P2 type of ASTM E208:2020
Sampling positions of test specimens	1/2 of thickness and side-section 
Length direction of test specimen	Parallel to the final rolling direction of test plate
Regression equation	$T_{Kca}=\alpha+\beta\cdot T_{NDT}^{side}+\gamma\cdot t^{1.5}$ T_{Kca}: Temperature at K_{ca} of 6,000N/mm$^{3/2}$ or K_{ca} of 8,000N/mm$^{3/2}$, (℃) T_{NDT}^{side} : Nil-ductility transition temperature obtained by side-section drop weight test, (℃) t : thickness α, β, γ(1): constant
Notes	(1) α, β and γ are to be determined by comparing small-scale test results with brittle crack arrest test results.

Annex 6 Crack Arrest Measures for Extremely Thick Steel Plates

1 According to the thickness and yield strength of the hatch coaming top plating and side plating in Table A6-1, the requirements of crack arrest measures for extremely thick steel plates are given. The thickness and yield strength shown in Table A6-1 are not applicable for the upper deck.

2 If the as built thickness of the hatch coaming top plating and side plating is below the values contained in the table, countermeasures are not necessary regardless of the thickness and yield strength of the upper deck plating.

Measures for Extremely Thick Steel Plates **Table A6-1**

Yield Strength (N/mm^2)	Thickness (mm)	Option	Measures			
			1	2	3+4	5
355	$50 < t \leqslant 85$	-	N.A.	N.A.	N.A.	N.A.
	$85 < t \leqslant 100$	-	X	N.A.	N.A.	N.A.
390	$50 < t \leqslant 85$	-	X	N.A.	N.A.	N.A.
	$85 < t \leqslant 100$	A	X	N.A.	X	X
		B	X*	X	N.A.	X
460 (FCAW)	$50 < t \leqslant 100$	A	X	N.A.	X	X
		B	X*	X	N.A.	X
460 (EGW)	$50 < t \leqslant 100$	-	X	N.A.	X	X

"X" means "To be applied".

"N.A." means "Need not to be applied".

"A", "B": selectable options.

*: See 4.9.1(2)e of the Guidelines.

Measures:

1. NDT other than visual inspection on all target block joints (during construction): See 4.5 of the Guidelines;

2. Periodic NDT other than visual inspection on all target block joints (after delivery): See 4.6 of the Guidelines;

3. Brittle crack arrest design against straight propagation of brittle crack along weldline to be taken (during construction): See 4.9.1(2)b, c or d of the Guidelines;

4. Brittle crack arrest design against deviation of brittle crack from weldline (during construction): See 4.9.1(1)a of the Guidelines;

5. Brittle crack arrest design against propagation of cracks from other welds such as fillets and attachment welds (during construction): See 4.9.1(1)a of the Guidelines.