



GUIDANCE NOTES
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CHINA CLASSIFICATION SOCIETY

**GUIDELINES FOR APPLICATION OF
THICK HIGHER STRENGTH STEEL
PLATES FOR SHIPS**

2020

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CHAPTER 1 GENERAL

1.1 Application

1.1.1 The Guidelines define the requirements on higher strength hull structural steels with a specified minimum yield strength of 460 N/mm².

1.1.2 The Guidelines define the requirements on brittle crack arrest steels with a specified minimum yield strength of 355 N/mm², 390 N/mm² and 460 N/mm².

1.1.3 The Guidelines identify when measures for the prevention of brittle fracture of extremely thick 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/mm².

(3) Brittle crack arrest steels (BCA) 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/mm².

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 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 W-01 Marine rolled steels of CCS Guidelines for Survey of Marine Products.

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)	0.015 ^{①②}
Nb	0.02 – 0.05 ^{②③}
V	0.05 – 0.10 ^{②③}
Ti max.	0.02 ^{②③}
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 steels^①

Table 2.2.2

Supply condition	Grade	Yield Strength R_{eH} (N/mm ²) min.	Tensile Strength R_m (N/mm ²)	Elongation A_5 (%) min.	Charpy V-notch impact test			
					Test Temp. (°C)	Average Impact Energy (J) min.		
						50 < t ≤ 70	70 < t ≤ 85	85 < t ≤ 100
				Longitudinal		Longitudinal	Longitudinal	
TMCP ^②	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 J-01 Welding consumables of CCS Guidelines for Survey of Marine Products.

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			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.

2.5 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/mm².

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

2.6.4 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.

2.6.5 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/mm², 390 N/mm² and 460 N/mm² 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 over 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 W-01 Marine rolled steels of CCS Guidelines for Survey of Marine Products.

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.	0.02 ^④		0.02 ^④
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.
- 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 grade ^①	Thickness range (mm)	Brittle crack arrest properties ^{②⑥}	
		Brittle Crack Arrest Toughness Kca at -10 °C (N/mm ^{3/2}) ^{③④}	Crack Arrest Temperature CAT (°C) ^④
BCA1	50 < t ≤ 100	≥6,000 min.	≤-10
BCA2	80 < t ≤ 100 ^⑦	≥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 $K_{ca}=8,000 \text{ N/mm}^{3/2}$ 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.
- 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”).

3.2.4 The small size test method is to be put forward by the steel manufacturer, and at the same time the test evidence showing relevance of the small size test to the big size test of Annex 3 or 4 is to be provided.

3.2.5 The small size test method may be in accordance with Annex 5 side drop weight test or small size test method approved by CCS. Even if the side drop weight test of annex 5 is selected, the evidence showing relevance to the big size test still needs to be provided by the steel manufacturer.

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 The requirements for welding procedure qualification test for brittle crack arrest steels is to be in accordance with the relevant requirements for each steel grade excluding suffix “BCA1” or “BCA2”, except for 3.4.3 below.

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.

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/mm², 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 be specially considered 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/mm² 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.

4.4.3 Special consideration is to be paid to the construction details where extremely thick steel plates are applied to structural members such as connections between outfitting and hull structures. Connections details are to be in accordance with the relevant requirements of CCS.

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 relevant CCS guidelines.

4.5.2 Visual inspection and 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 Chapter 7 of CCS Guidelines for Inspection of Hull Welds (for ships contracted for construction before 1 July 2021) or Appendix 1 of PART THREE of the Rules for Materials and Welding (for ships contracted for construction on or after 1 July 2021). 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.

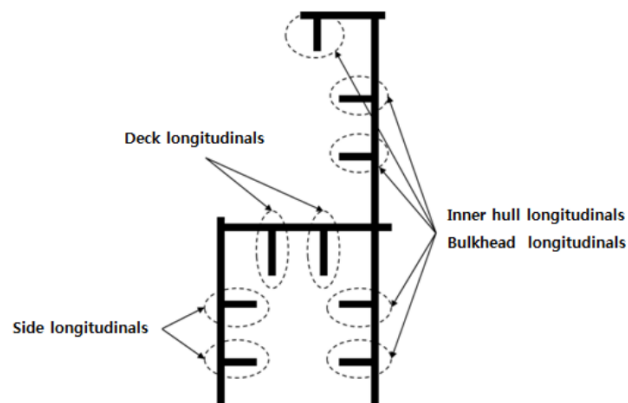


Figure 4.5.2 Upper Flange Longitudinal Structural Members

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.

4.6 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 CCS Guidelines for Inspection of Hull Welds (for ships contracted for construction before 1 July 2021) or Appendix 1^① of PART THREE of the Rules for Materials and Welding (for ships contracted for construction on or after 1 July 2021).

4.6.3 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 every five years.

4.6.4 Where UT is carried out, acceptance criteria of UT are to be specially considered by CCS.

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

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. Otherwise other means for preventing the crack initiation and propagation are to be agreed with CCS.

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.

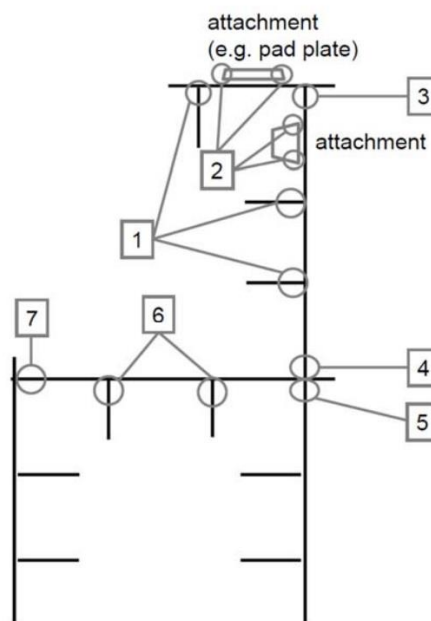
4.8 Brittle crack arrest design

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 block-to-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. Other measures may be considered and accepted for review by CCS.

- (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 and PAUT are to be approved by CCS.

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 EH47 steels.

1.2 Unless otherwise specified in this Annex, the approval of 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 W-01 Marine rolled steels of CCS Guidelines for Survey of Marine Products.

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

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°C . 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 national standards such as CB/T 4364-2013 or JIS Z 3158.

(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°C , 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 W-01 Marine rolled steels of CCS Guidelines for Survey of Marine Products 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 EH40 or EH36 brittle crack arrest steels in W-01 Marine rolled steels of CCS Guidelines for Survey of Marine Products and/or provisions for EH47 brittle crack arrest steels in Annex 1 of the Guidelines, satisfying requirements for steels without suffix “BCA1” or “BCA2”.

2 Approval Application

2.1 Documents to be submitted

2.1.1 In addition to documents required in W-01 Marine rolled steels of CCS Guidelines for Survey of Marine Products, 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. The approval of EH47 brittle crack arrest steels cannot cover EH40 brittle crack arrest steels. If the manufacturing process and mechanism to ensure the brittle crack arrest properties for the steels intended for approval are same, EH40 brittle crack arrest steels can cover EH36 brittle crack arrest steels.

3.1.2 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 and side drop weight tests are to be carried out in accordance with Annex 5, in addition to the approval tests specified in W-01 Marine rolled steels of CCS Guidelines for Survey of Marine Products (for EH40 or EH36 brittle crack arrest steels) and/or Annex 1 of the Guidelines (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, method of manufacture and condition of supply 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 Annex 2 and W-01 Marine rolled steels of CCS Guidelines for Survey of Marine Products.

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 The test specimens and repeat test specimens are to be taken from the same steel plate.

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 Side drop weight tests

3.4.1 The test specimens of side drop weight tests are to be taken from the same rolled piece for test specimens of the brittle crack arrest tests.

3.4.2 The side non-plastic transition temperature of the material is tested in accordance with Annex 5 during the side drop weight test.

3.5 Other tests

3.5.1 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, together with side drop weight test report.

5 Marks

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

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}

Setting a temperature gradient in the width direction of a test specimen, and applying uniform stress to the test specimen, strike the test specimen to initiate a brittle crack from the mechanical notch at the side of the test specimen and causes crack arrest (temperature gradient type arrest testing). Using the stress intensity factor, calculate the brittle crack arrest toughness, K_{ca} , from the applied stress and the arrest crack length. This value is the brittle crack arrest toughness at the temperature of the point of crack arrest (arrest temperature). To obtain K_{ca} at a specific temperature followed by the necessary evaluation, the method specified in Appendix A of this Annex 3 can be used.

As a method for initiating a brittle crack, a secondary loading mechanism can also be used (see Appendix B of this Annex 3 “Double tension type arrest test”).

1 Scope

This Annex 3 specifies the test method for brittle crack arrest toughness (i.e. K_{ca}) of steel using fracture mechanics parameter. This Annex 3 is applicable to hull structural steels with the thickness over 50 mm and not greater than 100 mm.

2 Symbols and their significance

The symbols and their significance used in this standard are shown in Table A3-1.

Symbols and their significance

Table A3-1

Symbol	Unit	Significance
a	mm	Crack length or arrest crack length
E	N/mm ²	Modulus of longitudinal elasticity
E_i	J	Impact energy
E_s	J	Strain energy stored in a test specimen
E_t	J	Total strain energy stored in tab plates and pin chucks
F	MN	Applied load
K	N/mm ^{3/2}	Stress intensity factor
K_{ca}	N/mm ^{3/2}	Arrest toughness
L	mm	Test specimen length
L_p	mm	Distance between the loading pins
L_{pc}	mm	Pin chuck length
L_{tb}	mm	Tab plate length
T	°C	Temperature or arrest temperature
t	mm	Test specimen thickness
t_{tb}	mm	Tab plate thickness
t_{pc}	mm	Pin chuck thickness
W	mm	Test specimen width
W_{tb}	mm	Tab plate width
W_{pc}	mm	Pin chuck width
x_a	mm	Coordinate of a main crack tip in the width direction
x_{br}	mm	Coordinate of the longest branch crack tip in the width direction

y_a	mm	Coordinate of a main crack tip in the stress loading direction
y_{br}	mm	Coordinate of the longest branch crack tip in the stress loading direction
σ	N/mm ²	Applied stress
σ_{y0}	N/mm ²	Yield stress at room temperature

3 Testing equipment

The following specifies the testing machine needed for conducting the brittle crack arrest test. Testing machine is used to apply tensile force to an integrated specimen, and impact equipment is used to generate a brittle crack on the test specimen.

3.1 Testing machine

3.1.1 Loading method

3.1.1.1 Tensile load to an integrated specimen shall be hydraulically applied. The loading method to an integrated specimen using the testing machine shall be of a pin type. The stress distribution in the plate width direction shall be made uniform by aligning the centres of the loading pins of both sides and the neutral axis of the integrated specimen.

3.1.2 Loading directions

3.1.2.1 The loading directions shall be either vertical or horizontal. In the case of the horizontal direction, test specimen surfaces shall be placed either perpendicular to the ground.

3.1.3 Distance between the loading pins

3.1.3.1 The distance between the loading pins shall be approximately $3.4W$ or more, where W is the width of the test specimen. Since the distance between the loading pins sometimes has an effect on the load drop associated with crack propagation, the validity of the test results is determined by the judgment method described in 7.1.

3.2 Impact equipment

3.2.1 Impact methods

Methods to apply an impact load to an integrated specimen shall be of a drop weight type or of an air gun type.

The wedge shall be hard enough to prevent significant plastic deformation caused by the impact. The wedge thickness shall be equal to or greater than that of the test specimen, and the wedge angle shall be greater than that of the notch formed in the test specimen and have a shape capable of opening up the notch of the test specimen.

4 Test specimens

4.1 Test specimen shapes

4.1.1 The standard test specimen shape is shown in Figure A3-1. Table A3-2 shows the ranges of test specimen thicknesses, widths and width-to-thickness ratios.

The test specimen length shall be, in principle, equal to or greater than its width.

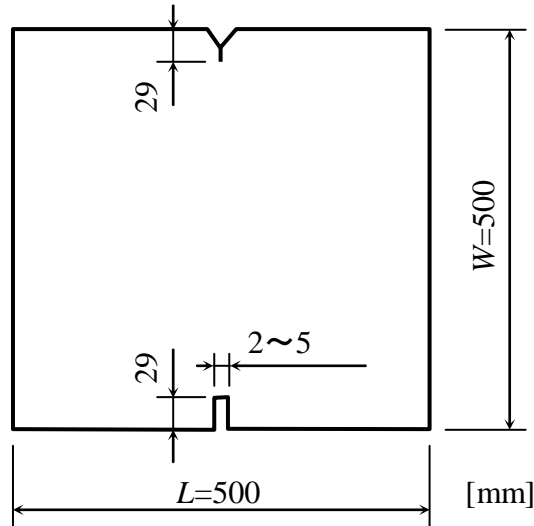


Figure A3-1 Standard test specimen shape

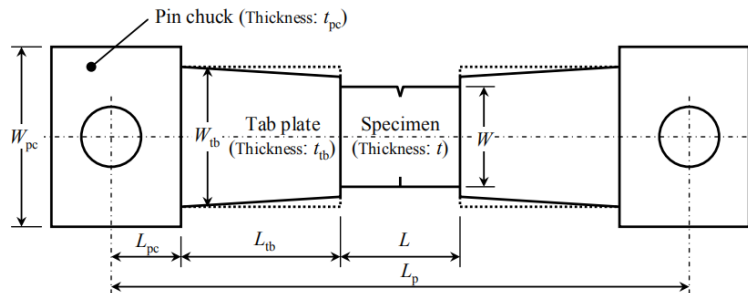
Dimensions of test specimens

Table A3-2

Test specimen thickness, t	$50 \text{ mm} < t \leq 100 \text{ mm}$
Test specimen width, W	$350 \text{ mm} \leq W \leq 1000 \text{ mm}$ (Standard width: $W = 500 \text{ mm}$)
Test specimen width/test specimen thickness, W/t	$W/t \geq 5$

4.2 Shapes of tab plates and pin chucks

4.2.1 The definitions of the dimensions of the tab plates and pin chucks are shown in Figure A3-2. Typical examples are shown in Figure A3-3.

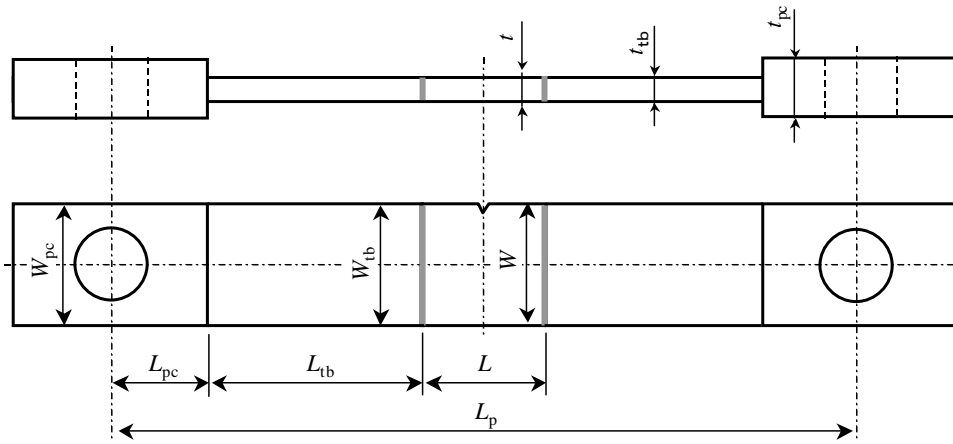


(a) Single-pin type

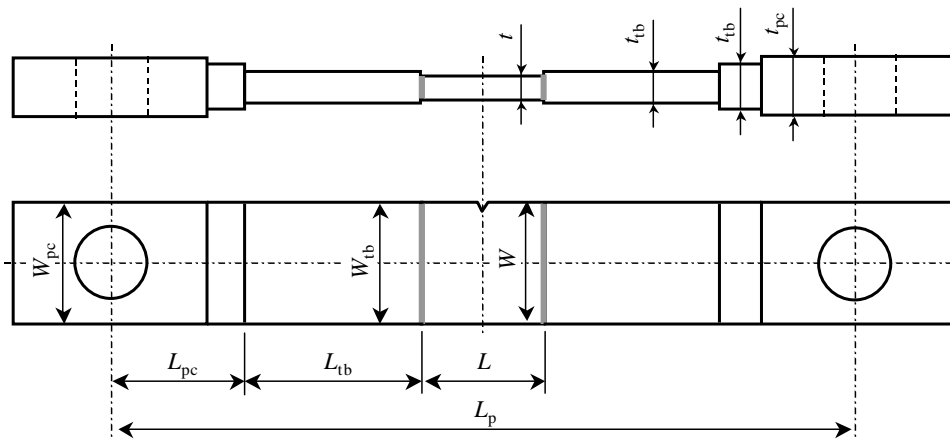


(b) Double-pin type

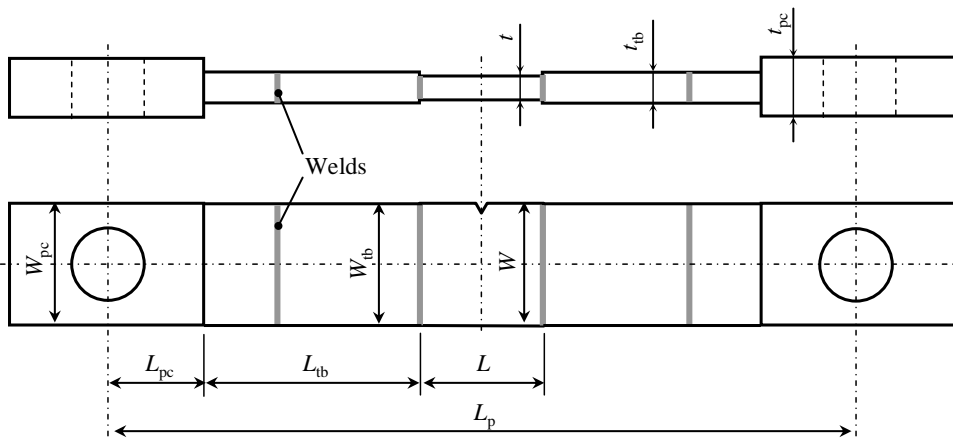
Figure A3-2 Definitions of dimensions of tab plates and pin chucks



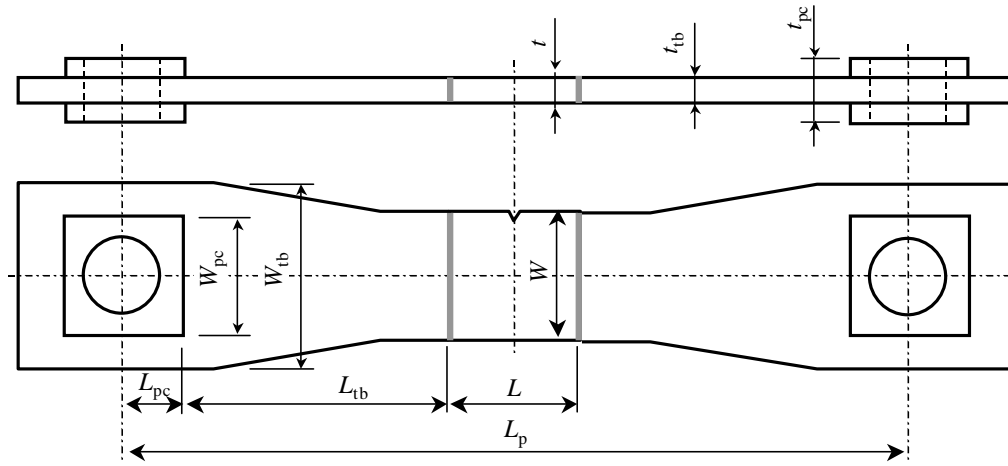
(a) Example 1



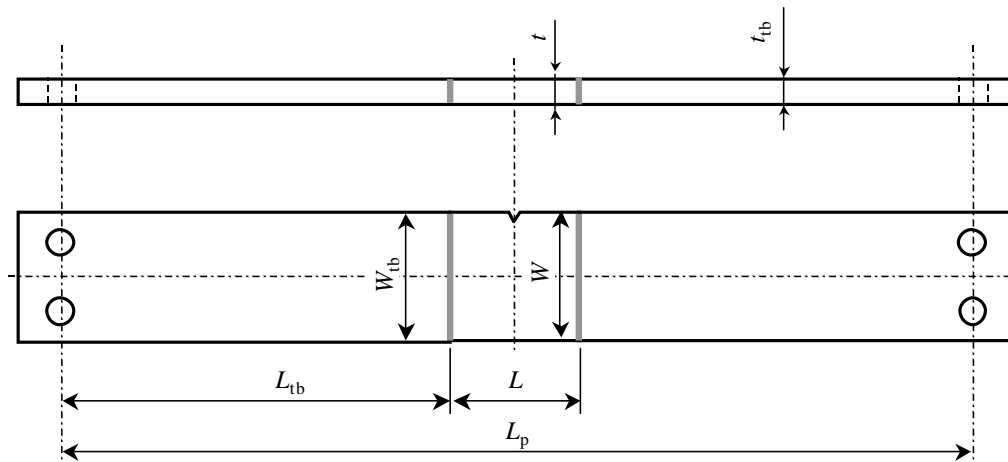
(b) Example 2



(c) Example 3



(d) Example 4



(e) Example 5

Figure A3-3 Examples of shapes of tab plates and pin chucks

4.2.2 Tab plates

4.2.2.1 The tolerances of tab plate dimensions are shown in Table A3-3. When the lengths of the tab plates attached to both ends of a test specimen are different, the shorter length shall be used as the tab length, L_{tb} .

Tolerances of tab plate dimensions

Table A3-3

Tab plate thickness, t_{tb}	$0.8t \leq t_{tb} \leq 1.5t$
Tab plate width, W_{tb}	$W \leq W_{tb} \leq 2.0W$
Total length of a test specimen and tab plates, $L + 2L_{tb}$ (Total length of a test specimen and a single tab plate, $L + L_{tb}$)	$L + 2L_{tb} \geq 3.0W$ $(L + L_{tb} \geq 2.0W)$
Tab plate length (L_{tb}) / Tab plate width (W)	$L_{tb}/W \geq 1.0$

4.2.3 Pin chucks

4.2.3.1 The pin chuck width, W_{pc} , shall be in principle equal to or more than the tab plate width, W_{tb} . The pin chucks shall be designed to have a sufficient load bearing strength. When pin chucks

attached to both ends of an integrated specimen are asymmetric, the length of the shorter one shall be used as the pin chuck length, L_{pc} .

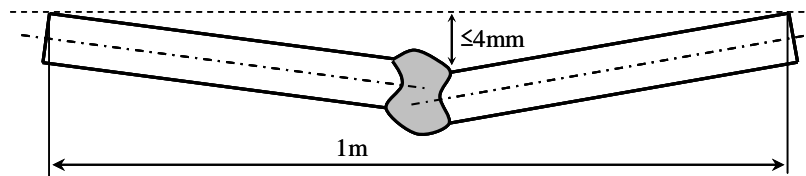
4.2.3.2 The distance between the pins, L_p , is obtained from the equation (1). In the case as shown in Figure A3-3 (e), Example 5, L_p is obtained by setting $L_{pc} = 0$.

$$L_p = L + 2L_{tb} + 2L_{pc} \quad (1)$$

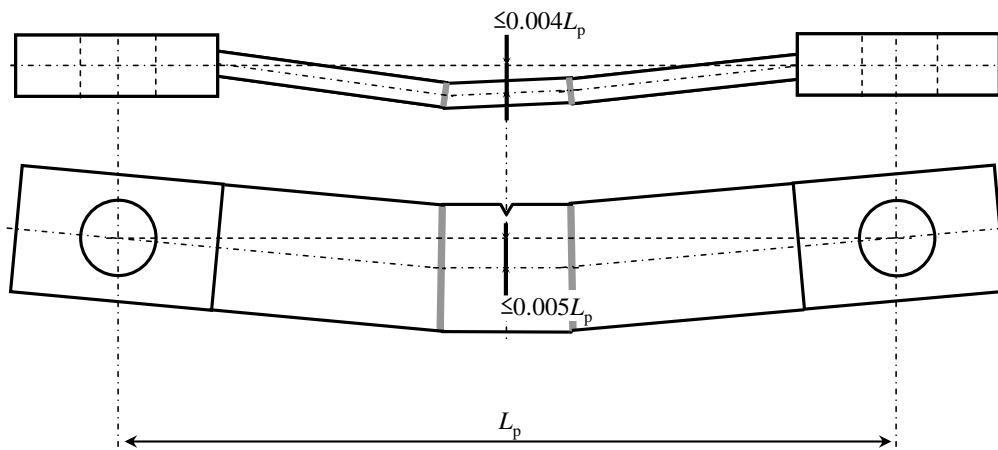
4.3 Welding of test specimen and tab plates

4.3.1 Test specimen, tab plates, and pin chucks shall be connected by welding. The welds shall have a sufficient force bearing strength.

4.3.2 As shown in Figure A3-4 (a), the flatness (angular distortion, linear misalignment) of the weld between a test specimen and a tab plate shall be 4 mm or less per 1 m. In the case of preloading, however, it is acceptable if the value after preloading satisfies this condition. As shown in Figure A3-4 (b), the accuracy of the in-plane loading axis shall be 0.5% or less of the distance between the pins, and the accuracy of the out-of-plane loading axis shall be 0.4% or less of the distance between the pins.



(1) Flatness of weld between test specimen and tab plate



(2) Accuracy of in-plane and out-of-plane loading axes

Figure A3-4 Dimensional accuracy of weld between test specimen and tab plate

5 Test methods

The following specifies methods for conducting the arrest toughness test.

5.1 Temperature control methods

5.1.1 A predetermined temperature gradient shall be established across a test specimen width by soldering at least nine thermocouples to the test specimen for temperature measurement and control.

5.1.2 Temperature gradient shall be established in accordance with the following conditions (1) through (3).

(1) A temperature gradient of 0.25 - 0.35°C/mm shall be established in a test specimen width range of 0.3W - 0.7W. When measuring the temperatures at the centre position of the test specimen thickness, it shall be kept within ±2°C for 10 minutes or more, whereas when measuring the temperatures on the front and back surface positions of the test specimen, it shall be kept within ±2°C for (10+0.1t [mm]) minutes or more taking account of the time needed for soaking to the centre. If the temperature gradient at 0.3W - 0.7W is less than 0.25°C/mm, crack arrest may become difficult, and if the gradient is larger than 0.35°C/mm, the obtained arrest toughness may be too conservative.

(2) At the test specimen width centre position (i.e., 0.5W), and in the range of ±100 mm in the test specimen length direction, the deviation from the temperature at the centre position in the length direction shall be controlled within ±5°C. However, when temperature measurement is not performed at the centre position in the length direction, the average temperature at the closest position shall be used as the temperature at the centre position in the length direction.

(3) At the same position in the width direction, the deviation of the temperature on the front and back surfaces shall be controlled within ±5°C.

5.2 Crack initiation methods

5.2.1 Impact energy shall be applied to a test specimen to initiate a crack. However, if the energy is excessive, it may influence on the test results. In that case, the results shall be treated as invalid data in accordance with the judgment criteria specified in 7.2. It is desirable to use equation (2) and Figure A3-5 as guides for obtaining valid data.

$$\frac{E_i}{t} \leq \min(1.2\sigma - 40, 200) \dots\dots\dots(2)$$

Where the variables have the following units: E_i [J], t [mm], and σ [N/mm²], and *min* means the minimum of the two values.

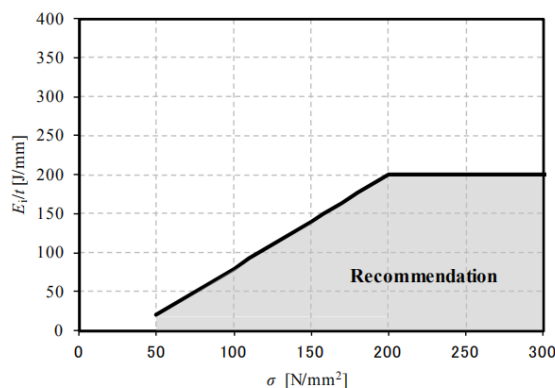


Figure A3-5 Recommended range of impact energy

6 Test procedures

The following specifies the procedures for testing brittle crack arrest toughness.

6.1 Pretest procedures

- (1) Install an integrated specimen in the testing machine.
- (2) Mount a cooling device on the test specimen. A heating device may also be mounted on the test specimen.
- (3) Install an impact apparatus specified in 3.2, on the testing machine. Place an appropriate reaction force receiver as necessary.

Note: The above procedures (1) through (3) do not necessarily specify the order of implementation, and they may be completed, for example, on the day before the test.

- (4) After checking that all measured values of the thermocouples indicate room temperature, start cooling. The temperature distribution and the holding time shall be as provided in the specifications in 5.1.
- (5) Set an impact apparatus, as specified in 3.2 so that it can supply predetermined energy to the test specimen.

(6) Apply force to the test specimen until it reaches the predetermined value. This force is applied after temperature control to prevent autonomous crack initiation during force increase. Alternatively, temperature control may be implemented after loading. The loading rate and applied stress shall satisfy the conditions (a) and (b) described below, respectively.

(a) Loading rate

There is no specification of loading rate, but it shall be determined considering that an excessively slow loading rate may prolong the temperature control period, thereby allowing the temperature distribution to depart from the desired condition and an excessively fast loading rate may cause over-shooting of the load.

(b) Applied stress/yield stress ratio

Applied stress shall be within the range shown by equation.

$$\sigma \leq \frac{2}{3} \sigma_{Y0} \dots\dots\dots(3)$$

As a guide, a value equal to 1/6 of σ_{Y0} or more is desirable. If applied stress is larger than that specified by equation (3), the test may give a non-conservative result.

(7) To initiate a crack, the notch may be cooled further immediately before impact on the condition that the cooling does not disturb the temperature in the range of 0.3W - 0.7W. The test temperature in this case shall be the measured temperature obtained from the temperature record immediately before the further notch cooling.

(8) Record the force value measured by a force recorder.

6.2 Loading procedures

- (1) After holding a predetermined force for 30 seconds or more, apply an impact to the wedge using the impact apparatus. If a crack initiates autonomously and the exact force value at the time of the crack initiation cannot be obtained, the test is invalid.
- (2) After the impact, record the force value measured by the force recorder.
- (3) When the force after the impact is smaller than the test force, consider that crack initiation has occurred.

Note: An increase in the number of times of impact may cause a change in the shape of the notch of the test specimen. Since the number of impact has no effect on the value of brittle crack arrest toughness, no limit is

specified for the number of impact. However, because the temperature gradient is often distorted by impact, the test shall be conducted again, beginning from temperature control when applying repeated impact to the wedge.

(4) When crack initiation, propagation, and arrest are observed, remove the force.

6.3 Procedures after testing

(1) Remove the impact apparatus.

(2) Remove the cooling device, thermocouples, and strain gauges.

(3) Return the temperature of the test specimen to room temperature. For that purpose, the test specimen may be heat-tinted using a gas burner or the like. If it is necessary to prevent heating of the fracture surface, this method shall be avoided.

(4) After gas-cutting an uncracked ligament, use the testing machine to cause ductile fracture, as necessary. Alternatively, it is also possible to gas-cut the uncracked ligament after using the testing machine to develop a ductile crack to a sufficient length.

6.4 Observation of fracture surfaces

(1) Photograph the fracture surfaces and propagation path.

(2) Measure the longest length of the arrest crack tip in the plate thickness direction, and record the result as the arrest crack length. The arrest crack length shall include the notch length. In the case where a crack deviates from the direction vertical to the loading direction, the length projected to the plane vertical to the loading line is defined as the arrest crack length. In the following cases, however, judge the results according to the methods described for each case.

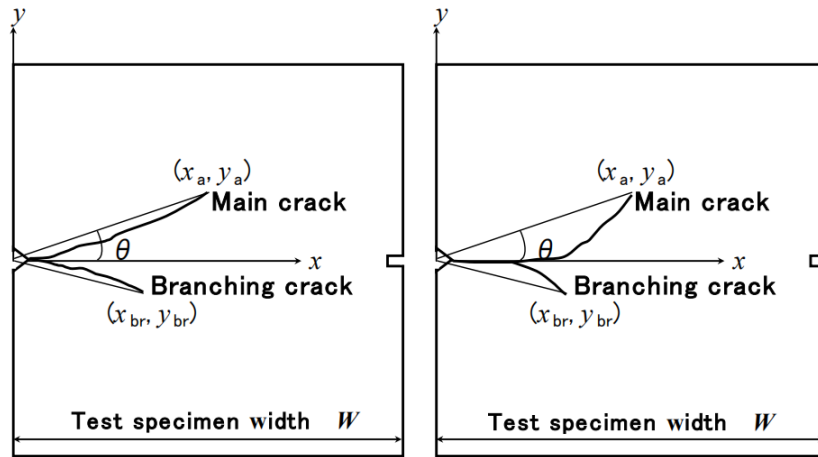
(a) Crack re-initiation

In the case where a brittle crack has re-initiated from an arrested crack, the original arrest position is defined as the arrest crack position. Here re-initiation is defined as the case where a crack and re-initiated cracks are completely separated by a stretched zone and brittle crack initiation from the stretched zone can be clearly observed. In the case where a crack continuously propagates partially in the thickness direction, the position of the longest brittle crack is defined as the arrest position.

(b) Crack branching

In the case where a crack deviates from the direction vertical to the loading direction, the length projected to the plane vertical to the loading line is defined as the arrest crack length. Similarly, in the case of crack branching, the length of the longest branch crack projected to the plane vertical to the loading line is defined as the branch crack length. More specifically, from the coordinates (x_a, y_a) of the arrest crack tip position and the coordinates (x_{br}, y_{br}) of the branch crack tip position shown in Figure A3-6, obtain the angle θ from the x-axis and define x_a as the arrest crack length, a . Here, x is the coordinate in the test specimen width direction, and the side face of the impact side is set as $x = 0$; y is the coordinate in the test specimen length direction, and the notch position is set as $y = 0$.

(3) Prepare a temperature distribution curve (line diagram showing the relation between the temperature and the distance from the test specimen top side) from the thermocouple measurement results, and obtain the arrest temperature T corresponding to the arrest crack length.



(a) Case of branching from notch

(b) Case of branching during brittle crack propagation

Figure A3-6 Measurement methods of main crack and branch crack lengths

7 Determination of arrest toughness

7.1 Judgment of arrested crack

When an arrested crack satisfies all of the conditions (a) through (d) below as shown in Figure A3-7, the length of the arrested crack determined by 6.4 is valid. If any of the conditions is not met, the arrest toughness calculated from 7.3 is invalid.

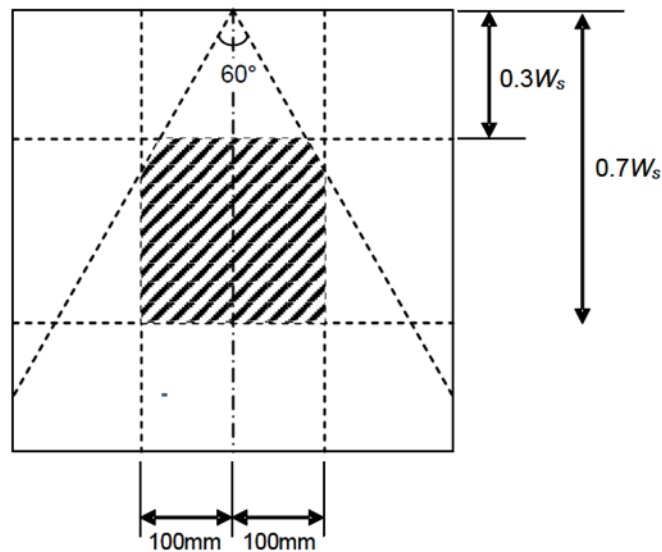


Figure A3-7 Necessary conditions of arrest crack position

(a) Conditions for crack propagation path:

All of the crack path from crack initiation to arrest shall be within the range shown in Figure A3-8. However, in the case where a main crack tip lies within this range but a part of the main crack passes outside the range, the arrest toughness may be assessed as valid if the temperature at the most deviated position of the main crack in the y direction is lower than that at $y = 0$, and also K for the main crack falls within $\pm 5\%$ of K for a straight crack of the same a . The calculation method of K s for the main crack and a straight crack is obtained from equation (4).

$$K = K_I \cos^3\left(\frac{\phi}{2}\right) + 3K_{II} \cos^2\left(\frac{\phi}{2}\right) \sin\left(\frac{\phi}{2}\right) \dots\dots\dots(4)$$

where: K = stress intensity factor;

K_I = stress intensity factor of mode I, applicable to crack opening mode;

K_{II} = stress intensity factor of mode II, applicable to crack shearing mode;

ϕ = angle of crack tip.

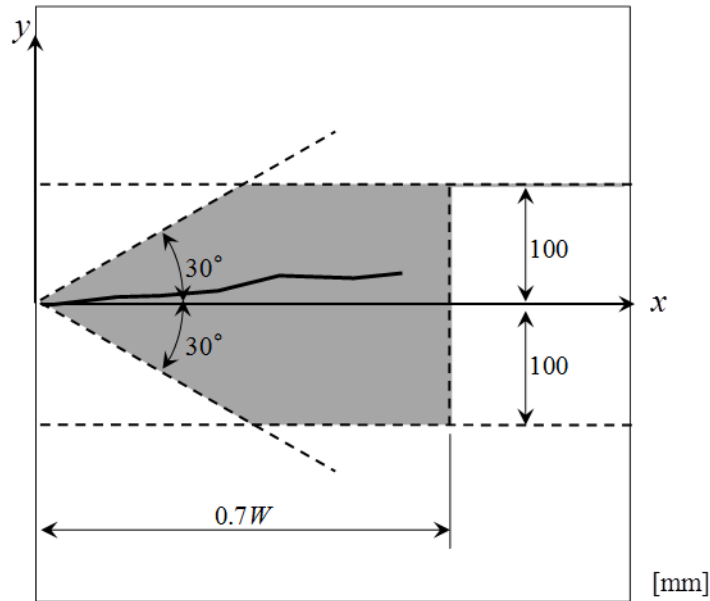


Figure A3-8 Allowable range of main crack propagation path

(b) Conditions for arrest crack length:

$$0.3 \leq \left(\frac{a}{W}\right) \leq 0.7 \quad (5)$$

$$\left(\frac{a}{t}\right) \geq 1.5 \dots\dots\dots(6)$$

$$\left(\frac{a}{L_p}\right) \leq 0.15 \quad (7)$$

Note: Equation (7) ensures minimal influence of force drop at the centre of the specimen which might be caused by crack propagation and reflection of the stress wave at the two ends of the specimen. However, application of equation (7) is not necessarily required if the strain and the crack length have been dynamically measured and the value of the strain at the time of arrest is 90% or more of the static strain immediately before crack initiation.

(c) Conditions for crack straightness:

$$|y_a| \leq 50 \text{ mm} \quad (8)$$

In the case where $50 \text{ mm} < |y_a| \leq 100 \text{ mm}$ and $|\theta| \leq 30^\circ$, the result is valid only when the temperature at $x = 0.5W$ and $y = \pm 100 \text{ mm}$ falls within $\pm 2.5^\circ\text{C}$ of that at $x = 0.5W$ and $y = 0$.

(d) Conditions for crack branching:

$$\left(\frac{x_{br}}{x_a} \right) \leq 0.6 \quad (9)$$

7.2 Assessment of impact energy

Impact energy shall satisfy equation (10). If it does not satisfy the equation, the value of arrest toughness calculated from the equations in 7.3 is invalid.

Conditions for impact energy:

$$\frac{E_i}{E_s + E_t} \leq \frac{5a - 1050 + 1.4W}{0.7W - 150} \quad \text{where} \quad 0.3 \leq \left(\frac{a}{W} \right) \leq 0.7 \quad (10)$$

where the variables have the following units: a [mm], and W [mm]. E_i is impact energy calculated from the equation (11). E_s and E_t are calculated from equations (12) and (13), respectively.

Note 1: If equation (10) is not satisfied, the influence of impact energy on the stress intensity factor is too large to obtain an accurate arrest toughness.

Note 2: In the case where the tab plates are multistage as shown in Figure A3-3 (b), calculate and total the strain energy of each tab plate using equation (12).

Note 3: In the case where tab plate widths are tapered as shown in Figure A3-3 (d), calculate the strain energy based on elastostatics.

$$E_i = m g h \dots\dots\dots(11)$$

$$E_s = \frac{10^9 F^2 L}{2E W t} \dots\dots\dots(12)$$

$$E_t = \frac{10^9 F^2}{E} \left(\frac{L_{tb}}{W_{tb} t_{tb}} + \frac{L_{pc}}{W_{pc} t_{pc}} \right) \dots\dots\dots(13)$$

where the variables have the following units: E_s [J], E_t [J], F [MN], E [N/mm²], L [mm], W [mm], and t [mm].

7.3 Calculation of arrest toughness

The arrest toughness, K_{ca} , at the temperature, T , shall be calculated from equation (14) using the arrest crack length, a , and the applied stress, σ , judged by 7.1. Calculate σ from equation (15).

$$K_{ca} = \sigma \sqrt{\pi a} \left[\frac{2W}{\pi a} \tan \left(\frac{\pi a}{2W} \right) \right]^{1/2} \dots\dots\dots(14)$$

$$\sigma = \frac{10^6 F}{W t} \dots\dots\dots(15)$$

where the variables have the following units: F [MN], W [mm], and t [mm].

If the conditions specified in 7.1 and 7.2 are not satisfied, the K_{ca} calculated from equation (14) is invalid.

8 Reporting

Using Table A3-4, the following items shall be reported:

- (1) Test material: Steel type and yield stress at room temperature;
- (2) Testing machine: Capacity of the testing machine;
- (3) Test specimen dimensions: Thickness, width, length, angular distortion, and linear misalignment;
- (4) Integrated specimen dimensions: Tab plate thickness, tab plate width, integrated specimen length including the tab plates, and distance between the loading pins;
- (5) Test conditions: Applied force, applied stress, temperature gradient, impact energy, and the ratio of impact energy to the strain energy stored in the integrated specimen (sum of test specimen strain energy and tab plate strain energy);
- (6) Test results:
 - (a) Judgment of arrest: Crack length, presence or absence of crack branching, main crack angle, presence or absence of crack re-initiation, and arrest temperature;
 - (b) Arrest toughness value;
- (7) Temperature distribution at moment of impact: Thermocouple position, temperature value, and temperature distribution;
- (8) Test specimen photographs: Crack propagation path (one side), and brittle crack fracture surface (both sides);
- (9) Dynamic measurement results: History of crack propagation velocity, and strain change at pin chucks.

Note: Item (9) shall be reported as necessary.

Report sheet for brittle crack arrest test results Table A3-4

Item	Details	Symbol	Conditions/ Results	Unit	Valid/ Invalid
(1) Test material	Steel type	—		—	—
	Yield stress at room temperature	σ_{Y0}		N/mm ²	—
(2) Test equipment	Testing machine capacity	—		MN	—
(3) Test specimen dimensions	Thickness	t		mm	
	Width	W		mm	
	Length	L		mm	
	Angular distortion + linear misalignment	—		mm/m	
(4) Integrated specimen dimensions	Tab plate thickness	t_{tb}		mm	
	Tab plate width	W_{tb}		mm	
	Test specimen length including a tab plate	$L + L_{tb}$		mm	
	Distance between loading pins	L_p		mm	
(5) Test conditions	Applied force	F		MN	
	Applied stress	σ		N/mm ²	

Item	Details	Symbol	Conditions/ Results	Unit	Valid/ Invalid	
	Temperature gradient	—		°C /mm		
	Impact energy	E_i		J		
	Ratio of impact energy to strain energy stored in integrated specimen	$E_i/(E_s+E_i)$		—		
(6) Test results	Judgment of crack propagation/arrest	Crack length	a		mm	
		Presence/absence of crack branching	—		—	—
		Ratio of branch crack length to main crack	x_{br}/x_a		—	
		Main crack angle	θ		(°)	
		Presence/absence of crack re-initiation	—		—	
		Temperature at crack arrest position	T		°C	
	Arrest toughness value	K_{ca}		N/mm ^{3/2}		
(7) Temperature distribution at moment of impact	Temperature measurement position	—	Attached	—	—	
	Temperature at each temperature measurement position	—	Attached	°C	—	
	Temperature distribution curve	—	Attached	—		
(8) Test specimen photographs	Crack propagation path	—	Attached	—		
	Brittle crack fracture surface (both sides)	—	Attached	—		
(9) Dynamic measurement results	History of crack propagation velocity	—	Attached	—		
	Strain change at pin chucks	—	Attached	—		

Appendix A Method for Obtaining K_{ca} at a Specific Temperature and the Evaluation

A.1 General

This Appendix specifies the method for conducting multiple tests specified in Annex 3 of the Guidelines to obtain K_{ca} value at a specific temperature T_D .

A.2 Method

A number of experimental data show dependency of K_{ca} on arrest temperature, as expressed by equation (A.1), where T_K [K] ($= T$ [°C] + 273), c and K_0 are constants.

$$K_{ca} = K_0 \exp\left(\frac{c}{T_K}\right) \dots\dots\dots (A.1)$$

The arrest toughness at a required temperature T_D [K] can be obtained by following the procedures below.

- (1) Obtain at least four valid K_{ca} data.
- (2) Approximating $\log K_{ca}$ by a linear expression of $1/T_K$, determine the coefficients $\log K_0$ and c for the data described in paragraph (1) by using the least square method.

$$\log K_{ca} = \log K_0 + c \frac{1}{T_K} \quad (A.2)$$

(3) Obtain the value of $K_{ca}/[K_0 \cdot \exp(c/T_K)]$ for each data item. When the number of data outside the range of 0.85 through 1.15 does not exceed, the least square method used in paragraph (2) is considered valid. Here is an integer obtained by rounding down the value. If this condition is not met, conduct additional tests to add at least two data and apply the procedure in paragraph (2) to the data.

(4) The value of $K_0 \exp(c/T_D)$ is defined as the estimated value of K_{ca} at T_D . The estimated value for the temperature corresponding to a specific value of K_{ca} can be obtained from $T_K = c/\log(K_{ca}/K_0)$. If the condition specified in paragraph (3) is not met, these estimated values are treated as reference values.

A.3 Evaluation

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°C) 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. 6,000 N/mm^{3/2} or 8,000 N/mm^{3/2}), as shown in Figure A3-A.1.

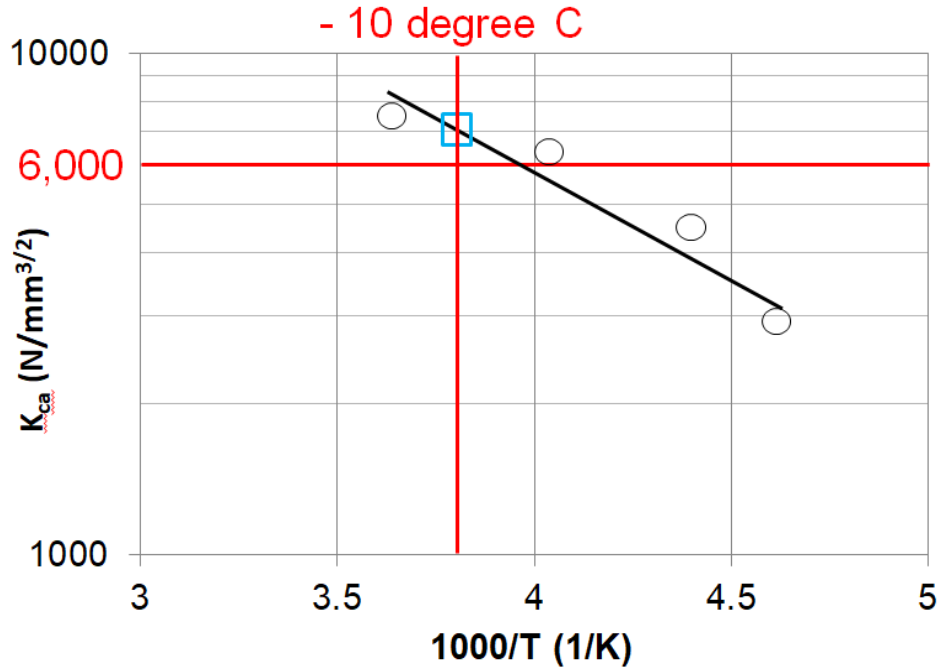


Figure A3-A.1 Example for evaluation of K_{ca} at -10°C

(2) The temperature corresponding to the required K_{ca} (e.g. $6,000\text{ N/mm}^{3/2}$ or $8,000\text{ N/mm}^{3/2}$) is located between the upper and lower limits of the arrest temperature, with the temperature corresponding to the required K_{ca} not higher than the evaluation temperature (i.e. -10°C), as shown in Figure A3-A.2.

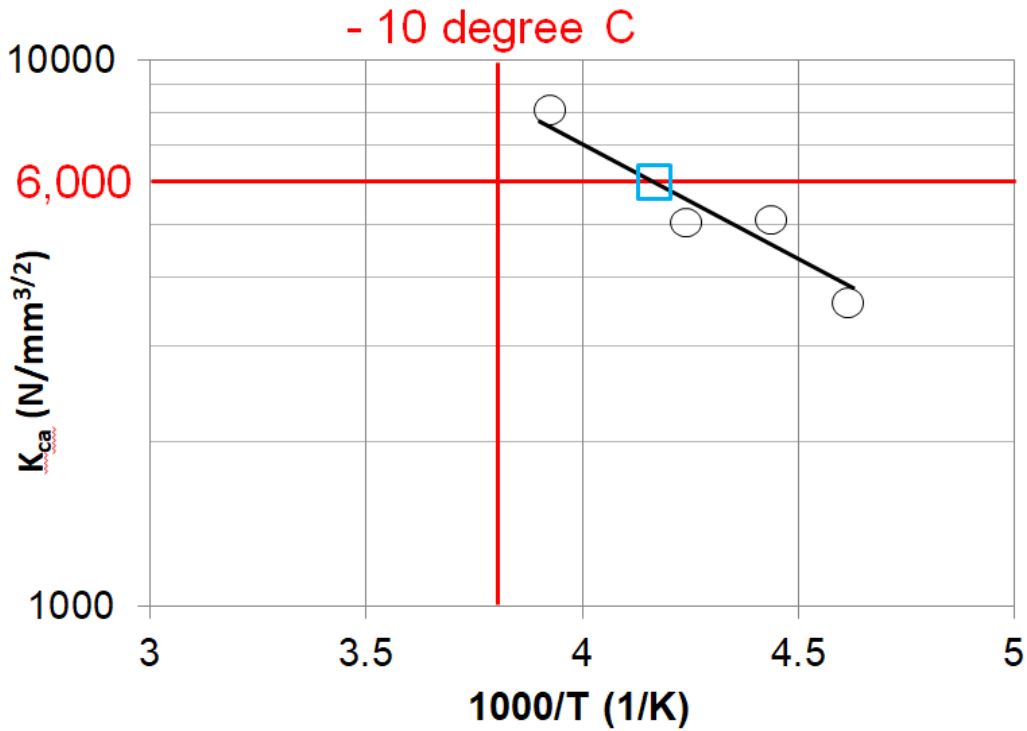


Figure A3-A.2 Example for evaluation of temperature corresponding to the required K_{ca}

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

Appendix B Double Tension Type Arrest Test

B1 Features of this test method

A double tension type arrest test specimen consists of a main plate and a secondary loading tab. The main plate is a test plate for evaluating brittle crack arrest toughness. The secondary loading tab is a crack starter plate for assisting a brittle crack to run into the main plate. After applying a predetermined tension force and a temperature gradient to the main plate, a secondary force is applied to the secondary loading tab by a secondary loading device to cause a brittle crack to initiate and run into the main plate. The arrest toughness is evaluated from the arrest temperature and the crack length in the main plate.

The narrow connection part of the main plate and the secondary loading tab in this test suppress the flow of the tension stresses of the secondary loading tab into the main plate. The values of arrest toughness obtained by this method can be considered the same as the results obtained by the brittle crack arrest toughness test specified in Annex 3.

The specifications described in Annex 3 are to be applied to conditions not mentioned in this Appendix B.

B2 Test specimen shapes

The recommended shapes of the entire double tension type arrest test specimen and the secondary loading tab are shown in Figures A3-B.1 and A3-B.2, respectively. Clause 4.2 of Annex 3 is applied to the shapes of the tab plates and pin chucks.

Note: Because of the narrowness of the connection part, slight crack deviation may lead to failure of the crack to enter the main plate. The optimum shape design of the secondary loading tab depends on the type of steel and testing conditions.

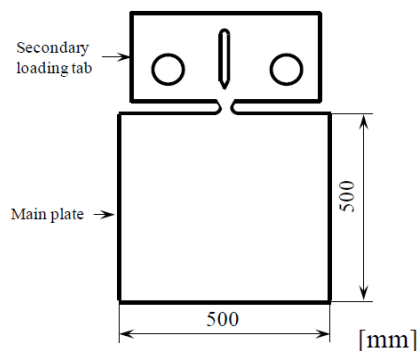


Figure A3-B.1 Example of shape of entire test specimen

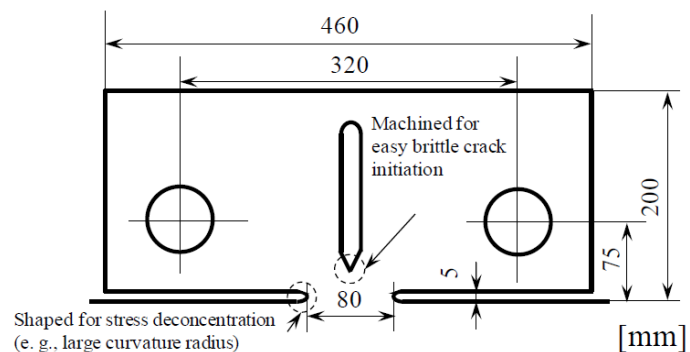


Figure A3-B.2 Example of shape of secondary loading

B3 Temperature conditions and temperature control methods

Establish a temperature gradient in the main plate in order to evaluate its brittle crack arrest toughness. The specifications for temperature gradients and methods for establishing the temperature gradient are described in clause 5 of Annex 3. In addition, in the double tension type arrest test, the secondary loading tab must be cooled. The secondary loading tab is cooled without affecting the temperature gradient of the main plate. As in the cooling method for test specimens

described in Annex 3, cooling may be applied using a cooling box and a coolant. The temperature of the secondary loading tab can be measured using thermocouples as described in Annex 3.

B4 Secondary loading method

A secondary loading device is used to apply force to the secondary loading tab. The secondary loading device is to satisfy the conditions below.

B4.1 Holding methods of secondary loading device

To avoid applying unnecessary force to the integrated specimen, the secondary loading device must be held in an appropriate way. Suspension type or floor type holding methods can be used. In the suspension type method, the secondary loading device is suspended and held by using a crane or a similar device. In the floor type method, the secondary loading device is lifted and held by using a frame or a similar device.

B4.2 Loading system

A hydraulic type loading system is most suitable for applying a force to the secondary loading tab. However, other methods may be used. Clause 4.2 of Annex 3 is applied to the shapes of the tab plates and pin chucks.

B4.3 Loading method

The method of loading the secondary loading tab is to be a pin type loading method. A loading method other than a pin type may be used by agreement among the parties concerned. The loading rate is not specifically specified because it does not have a direct influence on the crack arrest behavior of the main plate.

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 Annex 3.
- 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 A3-1 in Annex 3 with specific symbols for the isothermal test.

Nomenclature supplementary to Table A3-1

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-min}	mm	Minimum length between specimen edge and electron beam re-melting zone front
$L_{EB-s1, -s2}$	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 runaway
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 $\frac{2}{3}$ 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 3 of Annex 3.

4 Test specimens

4.1 Impact type crack initiation

4.1.1 Test specimens are to be in accordance with 4 of Annex 3, 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.

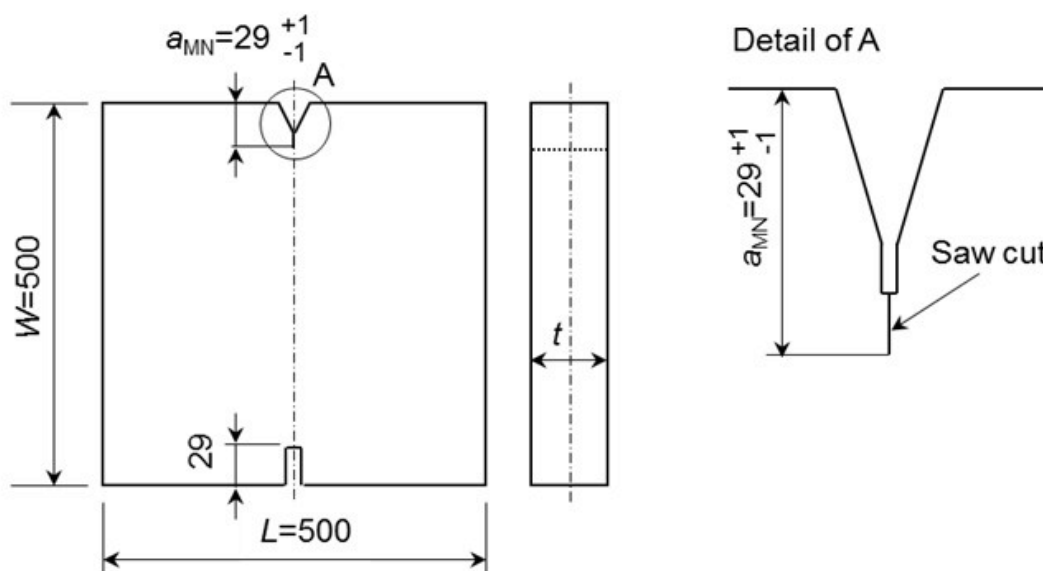


Figure A4-1 Test specimen dimensions for an impact type specimen

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 B in Annex 3 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 of 150 mm.

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.

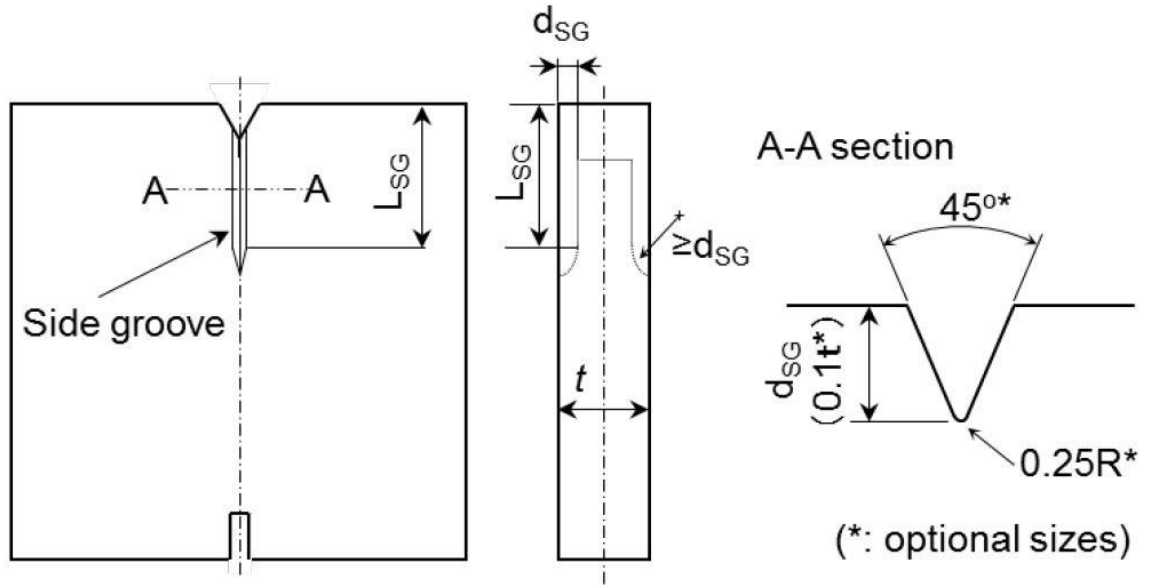


Figure A4-2 Side groove configuration and dimensions

4.5 Nominal length of embrittled zone

4.5.1 The length of embrittled zone is to be nominally equal to 150 mm in both systems of EBW and LTG.

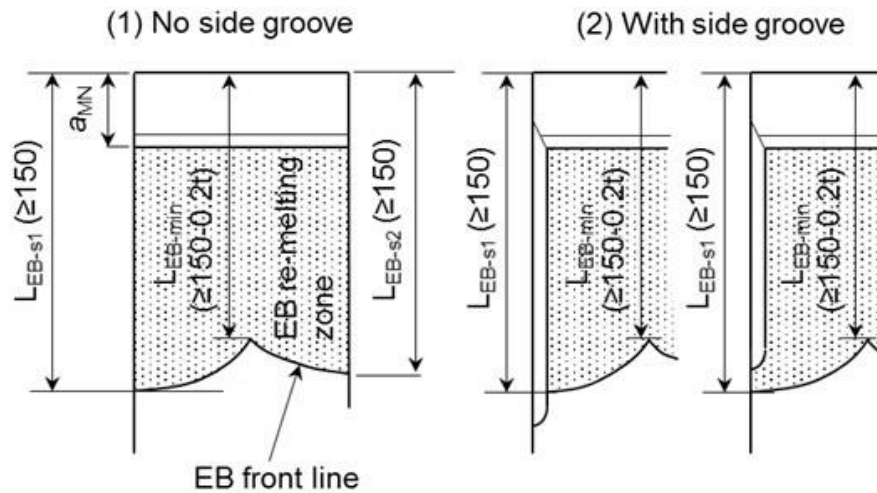


Figure A4-3 Definition of EBW length

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 4.2 of Annex 3. 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 4.3 of Annex 3.

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°C.

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.

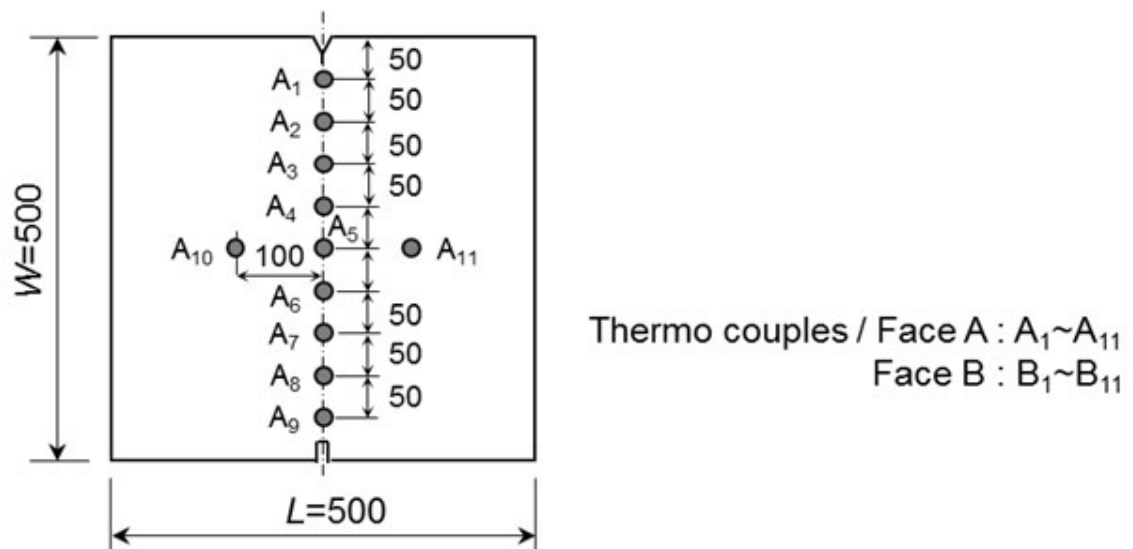


Figure A4-4 Locations of temperature measurement

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 $\pm 2^\circ\text{C}$ 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 $10 + 0.1 \cdot t[\text{mm}]$ 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 $0.3W \sim 0.7W$.

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.

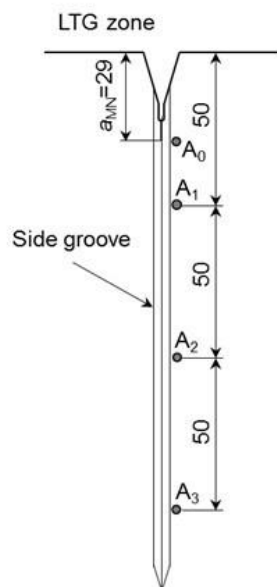


Figure A4-5 Detail of LTG zone and additional thermocouple A_0

5.2.4.2 The temperatures of the thermocouples across the range of $0.3W \sim 0.7W$ in both width and longitudinal directions are to be controlled within $\pm 2^\circ\text{C}$ 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 $0.3W \sim 0.7W$ have reached T_{target} , steady temperature control is to be kept at least for $10 + 0.1 * t[\text{mm}]$ 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 Two temperature measurements at A_2 , B_2 and A_3 , B_3 are to be satisfied the following requirements:

$$T \text{ at } A_3, T \text{ at } B_3 < T_{target} - 2^\circ\text{C}$$

$$T \text{ at } A_2 < T \text{ at } A_3 - 5^\circ\text{C}$$

$$T \text{ at } B_2 < T \text{ at } B_3 - 5^\circ\text{C}$$

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.

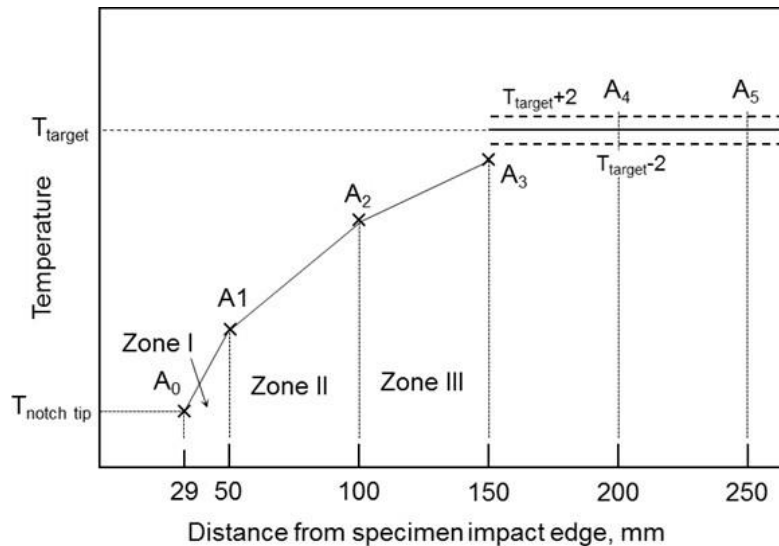


Figure A4-6 Schematic temperature gradient profile in LTG zone

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 A₀ to A₃.

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 6 of Annex 3 except that the applied stress is to be $\frac{2}{3}$ 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.

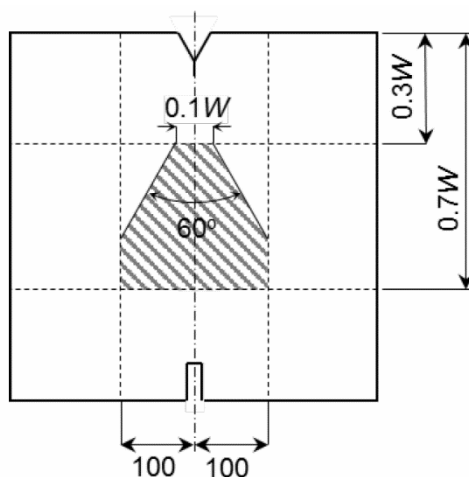


Figure A4-7 Allowable range of main crack propagation path

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-s1} , L_{EB-s2} and L_{EB-min} , which are defined in 4.5. When either or both of L_{EB-s1} and L_{EB-s2} are smaller than 150 mm, the test is to be invalid. When L_{EB-min} is smaller than $150\text{mm}-0.2t$, 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.

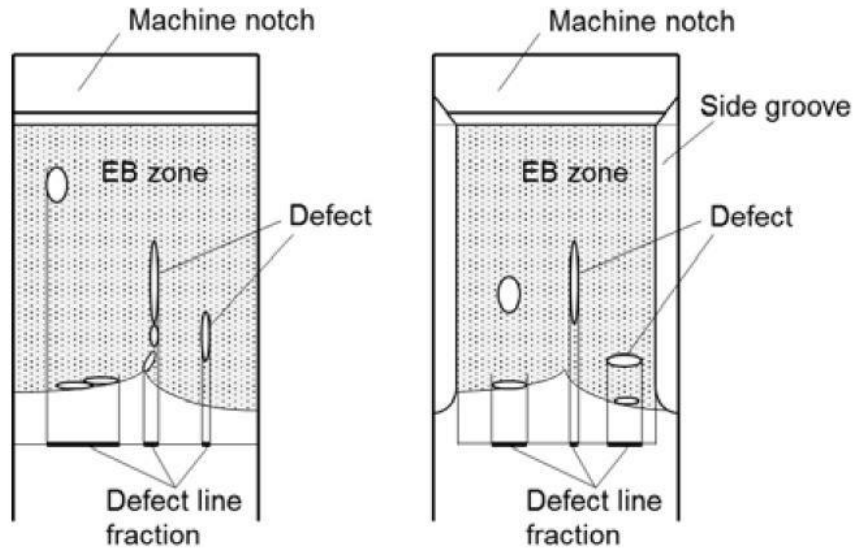


Figure A4-8 Counting procedure of defect line fraction

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 6.3 and 6.4 of Annex 3.

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-s1} , L_{EB-s2} or L_{EB-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 $0.3W \sim 0.7W$ in both width and longitudinal direction are in the range of $T_{target} \pm 2^\circ\text{C}$ at brittle crack initiation. If not, the test is to be invalid. However, the temperature

measurement at 0.3W (location of A₃ and B₃) in LTG system is to be exempted from this requirement.

8.1.2 If L_{EB-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 $T_{target} + 5^{\circ}C$.

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-s1} , L_{EB-s2} and L_{EB-min}
 - Judgment for shear lip thickness requirement

- Judgment whether brittle fracture appearance area continues from the EBW front line
- Judgment for EBW defects requirement
- Judgment for EBW lengths, L_{EB-s1} , L_{EB-s2} and L_{EB-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} :

- Judgment for a_{arrest} in the valid range ($0.3W < a_{arrest} \leq 0.7W$)
- 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 Side Drop Weight Test

1 The test material can usually be taken near the sampling position of conventional mechanical properties. The longitudinal axis of the specimen is parallel to the final rolling direction of the test plate, as shown in Figure A5-1.

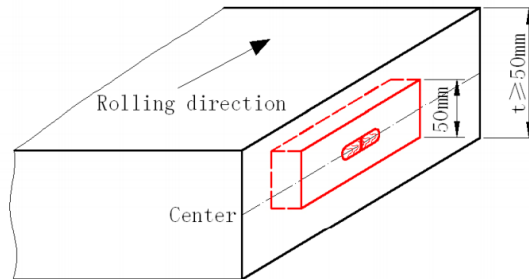


Figure A5-1 Side drop weight test sampling diagram

- 2 Test specimen dimensions and preparation are in accordance with specimen P2 in ASTM E208.
- 3 The test procedure is to be conducted in accordance with ASTM E208.
- 4 The product approval test requires determining the side non-plastic transition temperature of the material and taking a photo of the fracture surface.
- 5 For the test of product qualification, the side drop weight test is to be conducted only at the specified temperature. If no fracture occurred in a group of two specimens at the specified side drop weight test temperature, the test is qualified. If only one of the two specimens in a group fractures, a repeat test can be conducted. A group of two specimens are to be re-selected near the original sampling location and the repeat test is to be conducted at the original temperature. Neither of the two specimens is to fracture in the repeat test.

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	$50 < t \leq 85$	-	N.A.	N.A.	N.A.	N.A.
	$85 < t \leq 100$	-	X	N.A.	N.A.	N.A.
390	$50 < t \leq 85$	-	X	N.A.	N.A.	N.A.
		A	X	N.A.	X	X
	$85 < t \leq 100$	B	X*	N.A.**	N.A.	X
460 (FCAW)	$50 < t \leq 100$	A	X	N.A.	X	X
		B	X*	N.A.**	N.A.	X
460 (EGW)	$50 < t \leq 100$	-	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.

**: CCS may require periodic NDT after delivery in accordance with 4.6 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.