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CHINA CLASSIFICATION SOCIETY

GUIDELINES FOR INSPECTION OF THICK HIGHER STRENGTH STEEL PLATES FOR SHIPS

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Chapter 1 General

1.1 Purpose

1.1.1 The Guidelines have been specially developed for application of higher strength hull structural steels of which the minimum yield strength is 460 N/mm^2 used for large ships.

1.1.2 Brittle fracture can be liable to be observed in extremely thick higher strength steel plates of structure. Therefore, the Guidelines give measures of preventing brittle fracture of extremely thick higher strength steel plates to reduce the risk of brittle fractures that may be caused by application of extremely thick higher strength steel plates on larger size ships.

1.2 Application

1.2.1 The Guidelines are applicable to the approval and inspection of higher strength hull structural steels of minimum yield strength of 460 N/mm^2 that are supplied in Thermo-Mechanical Controlled Processing (TMCP) condition. For those supplied in normalized condition or quenched and tempered condition, special consideration is to be given by CCS.

1.2.2 The Guidelines are applicable to the approval and inspection of grade EH steel plates of higher strength hull structural steels with brittle crack arrest properties and thickness over 50 mm and not greater than 100 mm, having specified minimum yield strength of 390 N/mm^2 and 460 N/mm^2 respectively.

1.2.3 The Guidelines are applicable to identification for application of higher strength steel plates specified in 1.2.2 to longitudinal structural members (such as hatch side coaming, hatch coaming top and the attached longitudinals) in the upper deck region of container carriers, and provide preventive measures of brittle fracture.

1.2.4 Special consideration is to be given by CCS to the application of steel plates specified in 1.2.2 for structures other than those specified in 1.2.3 and steel plates with thickness greater than 100 mm.

1.3 Terms and definitions

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

(1) Extremely thick steel plate means the higher strength steel plate with thickness over 50 mm and not greater than 100 mm.

(2) Brittle crack arrest steel plate means the steel plate with relevant brittle crack arrest properties evaluated by the methods given in the Guidelines.

(3) Brittle crack arrest test means the test for evaluating the brittle crack arrest properties of steel plates, including standard ESSO test and double tension test.

(4) Brittle crack arrest toughness (K_{ca}) is a parameter of evaluating the brittle crack arrest properties of steel plates (in N/mm$^{3/2}$), to be measured by brittle crack arrest test.

(5) Crack arrest temperature (T_K) is a parameter of evaluating the brittle crack arrest properties of steel plates (in℃), meaning the temperature of the forefront of central crack when the moving cracks terminate at the main tensile plate of specimen under certain stress and temperature gradient in double tension test.

(6) Standard ESSO test means the brittle crack arrest test carried out in accordance with Appendix A.

(7) Double tension test means the brittle crack arrest test carried out in accordance with Appendix

B.

1.4 Test

1.4.1 Brittle crack arrest test is to be carried out at a laboratory acceptable to CCS.

1.4.2 Unless otherwise specified in the Guidelines, the test is to be carried out in accordance with the relevant provisions of PART ONE and PART THREE of CCS Rules for Materials and Welding.

Chapter 2 Approval of H47 Steel Plates

2.1 General requirements

2.1.1 This Chapter is applicable to the approval of higher strength hull structural steels (hereinafter referred to as "H47 steels") of specified minimum yield strength of 460 N/mm^2 and manufactured with thermo-mechanical controlled processing (TMCP). H47 steels are subdivided into four grades as A, D, E and F in accordance with different notch toughness and expressed as AH47, DH47, EH47 and FH47.

2.1.2 Unless otherwise specified in this Chapter, the approval of H47 steels is to be carried out in accordance with the relevant provisions of Section 1, Chapter 1 of PART TWO of CCS Guidelines for Survey of Marine Products.

2.1.3 Unless otherwise specified in this Chapter, the manufacture of H47 steels is to be carried out in accordance with the relevant provisions of Section 1, Chapter 3 of PART ONE of CCS Rules for Materials and Welding.

2.1.4 H47 steels are to be works approved by CCS.

2.2 Manufacture of steels

2.2.1 H47 steels are normally to be manufactured by electric furnace or basic oxygen process and to be fully killed and fine-grain treated.

2.2.2 H47 steels are normally to be supplied in TMCP condition. Other conditions of supply are to be specially considered by CCS.

2.3 Specifications of materials

2.3.1 The chemical compositions of ladle analysis of H47 steels are to comply with the requirements given in Table 2.3.1.

Chemical Compositions of H47 Steels (weight percentage %) Table 2.3.1

Grade	C	Mn	Si	S	P	Cr	Ni	Cu
AH47, DH47 EH47, FH47	0.14	2.00	0.55	0.01	0.02	0.30	1.50	0.50
	Al(acid soluble)	Nb		V	Ti	Mo	N	B
	≥0.015②	0.02~0.05③		0.05~0.10③	0.02③	0.25	0.015	0.003

Notes:

① Except Al, Nb and V, other elements are expressed with the maximum content.

② The total aluminum content is to be not less than 0.02% when it is determined instead of the acid soluble content.

③ When Al, Nb or V is used singly, the steel is to contain the specified minimum content of the grain refining element; and when used in combination, the specified minimum content of each element is not applicable.

④ The total content of Al, V and Ti is to be not more than 0.15%.

2.3.2 In addition to 2.3.1, the carbon equivalent and cold crack susceptibility of H47 steels supplied in TMCP condition are to be calculated in accordance with the chemical compositions of ladle analysis and to comply with the requirements given in Table 2.3.2.

Carbon Equivalent and Cold Crack Susceptibility of H47 Steels Table 2.3.2

Thickness of steel plates t(mm)	$t \leq 50$	$50 < t \leq 100$
Carbon equivalent C_{eq}	≤0.46	≤0.49
Cold crack susceptibility P_{cm}	≤0.20	≤0.22

Notes:

(1) The carbon equivalent is to be calculated using the following formula:

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

(2) The cold crack susceptibility is to be calculated using the following formula:

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

2.3.3 The H47 steels with thickness not more than 100 mm are to comply with the requirements given in Table 2.3.3.

Mechanical Properties of H47 Steels **Table 2.3.3**

Grade	Yield strength R_{eH} or $R_{p0.2}$ (N/mm^2) min.	Tensile strength R_m (N/mm^2)	Elongation A_5 (%) min.	Charpy V-notch impact test②			
				Test temp. (℃)	Average longitudinal impact energy (J) min.		
					t①≤70	70<t≤85	85<t≤100
AH47	460	570~720	17	0	53	64	75
DH47				-20			
EH47				-40			
FH47				-60			

Notes:

① t means thickness of steel plates, in mm.

② Generally, impact tests need only be made in the longitudinal direction, except when required by the purchaser or CCS; however, satisfactory transverse test results for steels are to be guaranteed by the manufacturer. The specified transverse impact value is 2/3 of the specified longitudinal impact value.

2.4 Approval test of materials

2.4.1 Unless otherwise specified in this Chapter, the approval of H47 steels, including procedures and test items, is to be carried out in accordance with the provisions of Section 1, Chapter 1 of PART TWO of CCS Guidelines for Survey of Marine Products.

2.4.2 One product with the maximum thickness and highest toughness grade within the range of approval is to be selected for the approval test.

2.4.3 The steels are to be tested in accordance with the following requirements:

(1) Test samples are to be taken from the rolled plate corresponding to the top of the ingot. In the case of rolled plate from continuous castings, test samples may be taken from the plate corresponding to the beginning or ending of each cast. The location of the test sample is to be at the end of the plate (top and bottom), approximately one quarter width from an edge, as shown in Figure 2.4.3.

(2) The following mechanical tests are to be carried out:

(a) Charpy V-notch impact test

i. Samples are to be taken with respect to the principal rolling direction of the plate at locations representing the top and bottom of the plate as follows:

longitudinal Charpy V-notch impact tests – Top and bottom,

transverse Charpy V-notch impact tests – Top only,

strain aged longitudinal Charpy V-notch impact test – Top only.

For Charpy V-notch impact tests, specimens are to be

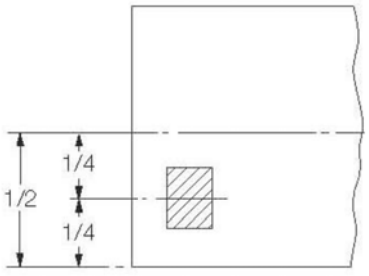


Figure 2.4.3
Sampling Positions of Test

taken at a position of 1/4 thickness of the samples. For materials with thickness over 40 mm, additional specimens are also to be taken at a position of 1/2 thickness of the samples. One set of 3 Charpy V-notch impact specimens is required for each impact test. The test temperature is to be the specified temperature of corresponding toughness grade of tested steel plates.

In addition to the determination of the energy value, the lateral expansion and the percentage crystallinity are also to be reported for the test results.

ii. The strain aged samples are to be strained to 5% followed by heating to 250℃ for 1 h prior to testing.

iii. Additionally at each location, Charpy V-notch impact tests are to be carried out with appropriate temperature intervals to properly define the full transition range.

(b) Deep notch test or Crack Tip Opening Displacement (CTOD) test is to be carried out and the result is to be reported.

(c) Drop weight test on the surface of the material is to be carried out and nil-ductility transition temperature is to be reported.

(3) In addition to the mechanical tests for base metal of steel plates required in (2), weldability test of steel plates is to be carried out in accordance with the following requirements:

(a) Charpy V-notch impact test

Charpy V-notch impact tests are to be taken at a position of 1/4 thickness from the plate surface on the face side of the weld with the notch perpendicular to the plate surface. One set of the specimens perpendicular to the weld is to be taken with the notch located at the fusion line and at a distance 2, 5 and minimum 20 mm from the fusion line. The fusion boundary is to be identified by etching the specimens with a suitable reagent before location of the notch is determined.

One additional set of the specimens is to be taken from the root side of the weld with the notch located at the same depth and at the same position as for the face side.

The impact test temperature is to be the same as for the base metal. The test result is to be not less than the specified minimum value of the base metal.

(b) Y-shape weld crack test (Hydrogen crack test) is to be carried out in accordance with recognized national standards such as GB 4675.1 and the recommended preheating temperature is to be reported.

(c) 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 of PART ONE of CCS Rules for Materials and Welding and the test result of heat affected zone is to be reported.

Chapter 3 Inspection of H47 Steel Plates

3.1 General requirements

3.1.1 H47 steels are to be manufactured in accordance with the approved procedures at works which have been approved by CCS.

3.1.2 H47 higher strength hull structural steels are to be subject to manufacturing inspection in accordance with this Chapter.

3.2 Deoxidation and chemical composition

3.2.1 H47 steels are to be fully killed and fine-grain treated, and the chemical composition of ladle analysis is to comply with the requirements of 2.3.1 and 2.3.2 of the Guidelines.

3.3 Condition of supply

3.3.1 The condition of supply of steels is generally to be TMCP.

3.4 Mechanical properties

3.4.1 For H47 steels, mechanical test specimens are to be taken and tested in accordance with following requirements:

(1) For AH47 or DH47 steels from the same cast and of similar dimensions, test specimens are to be taken from each batch of 50 t or fraction thereof. For EH47 or FH47 steels, test specimens are to be taken from each piece.

(2) Test specimens from each batch or piece are to include one tensile specimen and one set of three Charpy impact specimens. The flat test specimen given in Item 1 of Table 2.2.2.1 of Chapter 2, PART ONE of CCS Rules for Materials and Welding is to be used for tensile testing; for products over 40 mm in thickness, round test specimens given in Item 2 may be accepted, in which case the axis of the specimen is to be at 1/4 of the thickness.

(3) In case the thickness of products does not exceed 40 mm, the impact test specimen is to be close to the surface, i.e., its axis is to be 1/4 of the thickness from the rolled surface; where the thickness exceeds 40 mm, one additional set of impact test specimens is to be taken with the axis located at mid-plate thickness. The notch of the impact test specimen is to be cut in a face of the test specimen which was originally perpendicular to the rolled surface.

(4) Tests are to be carried out in accordance with the relevant provisions of Chapter 2 of PART ONE of CCS Rules for Materials and Welding. The test results are to comply with the requirements given in Table 2.3.3 of the Guidelines.

3.5 Marking and certification

3.5.1 Every item satisfactorily inspected is to be clearly marked, at least at one position, by the manufacturer with the CCS stamp and the following particulars:

(1) the manufacturer’s name or trade mark;

(2) the grade of steel;

(3) cast number and identification number or initials which will enable the full history of the item to be traced;

(4) the order number or other identification mark, if required by the purchaser.

The above stamps and marks are to be enhanced by proper methods for easy recognition.

3.5.2 The certificate of conformity for steels is to include the following particulars:

(1) purchaser's name and order number, and if known, the ship's name or machinery number for which the material is intended;

(2) address to which material is dispatched;

(3) description and dimensions of the material;

(4) specification or grade of the steel;

(5) cast number and chemical composition of ladle analysis;

(6) mechanical test results;

(7) condition of supply.

Chapter 4 Approval and Inspection of Brittle Crack Arrest Steels

4.1 General requirements

4.1.1 This Chapter is applicable to the approval and inspection of extremely thick higher strength grade EH steels of minimum yield strength of 390 N/mm^2 and 460 N/mm^2.

4.1.2 Unless otherwise specified in this Chapter, the brittle crack arrest steels are to comply with the relevant provisions of Section 3, Chapter 3 of PART ONE of CCS Rules for Materials and Welding and Chapter 2 of the Guidelines.

4.1.3 For the approved brittle crack arrest steels, the grade mark of the parent steel is to be suffixed with CA, e.g. EH47-CA.

4.2 Approval of brittle crack arrest steels

4.2.1 Unless otherwise specified in this Chapter, the approval of brittle crack arrest steels, including procedures and tests, is to be carried out in accordance with the provisions of Section 1, Chapter 1 of PART TWO of CCS Guidelines for Survey of Marine Products.

4.2.2 One test product with the maximum thickness to be approved is to be selected provided the approved target chemical composition range remains unchanged.

4.2.3 In addition to the mechanical tests of base metal required by 2.4.3 of the Guidelines, following tests are to be carried out:

(1) In accordance with Section 10, Chapter 2 of PART ONE of CCS Rules for Materials and Welding, P1 and P3 specimens are to be selected for drop weight test on the surface and at the center of the material. Nil Ductility Test Temperature (NDTT) of the material at the two locations is to be reported.

(2) Brittle crack arrest test is to be carried out in accordance with the requirements of Appendix A Standard ESSO Test or Appendix B Double Tension Test of the Guidelines. The test results are to comply with the requirement of $K_{ca} \geq$ 6,000 N/mm$^{3/2}$at -10℃ or $T_k \leq$ -10℃ under the stress conditions given in Table 4.2.3(2). When the steel plate is over 80 mm in thickness, relevant standards of acceptance are to be specially considered by CCS.

Loaded Stress Level in Test **Table 4.2.3(2)**

Specified minimum yield strength N/mm^2	Loaded stress level N/mm^2
390	257
460	282

4.3 Manufacturing inspection of brittle crack arrest steels

4.3.1 Unless otherwise specified in 4.3.2, the inspection of brittle crack arrest steels is to be carried out in accordance with the relevant provisions of Section 3, Chapter 3 of PART ONE of CCS Rules for Materials and Welding and Chapter 3 of the Guidelines.

4.3.2 Specimens are to be taken for fracture toughness test from each batch of products in accordance with the following requirements:

(1) Two test specimens for drop weight test are to be taken respectively, one for surface and the other for center, from each batch of steel plates in accordance with the provisions of Section 10, Chapter 2 of PART ONE of CCS Rules for Materials and Welding.

(2) The test temperature of plates is -60℃ (for surface) and -30℃ (for center). Test specimens are to be free from fractures (i.e. cracks propagate to one or two edges of the surface in tension).

(3) Where test results show fractures of two or more specimens, the batch of material is to be rejected. In case of fracture of one specimen, a retest is allowed. One set of two specimens same as the fractured one are to be taken adjacent to the original sampling position and the retest is to be carried out at the original test temperature. The two specimens are to be free from fractures in the retest.

4.4 Marking and certification

4.4.1 In addition to the requirements of 3.5 of the Guidelines for marking and certification of brittle crack arrest steels, the following provisions are to be complied with:

(1) Brittle crack arrest steels which have been satisfactorily inspected are to be marked with the grade mark of brittle crack arrest steel.

(2) The drop weight test results are to be indicated on certificates of brittle crack arrest steels.

Chapter 5 Application of Extremely Thick Higher Strength Steel Plates on Container Carriers

5.1 General requirements

5.1.1 This Chapter specifies requirements for application of extremely thick higher strength steel plates with specified minimum yield strength of 355 N/mm^2 to longitudinal structural members in the upper deck region of container carriers.

5.1.2 The welders engaged in welding of higher strength steels are to pass the qualification test required by Chapter 4 of PART THREE of CCS Rules for Materials and Welding.

5.1.3 Unless otherwise specified in this Chapter, the approval of welding procedures of extremely thick higher strength steel plates for ships is to be in accordance with the provisions of Section 3, Chapter 3 of PART THREE of CCS Rules for Materials and Welding.

5.2 Safety measures for extremely thick higher strength steel plates for container carriers

5.2.1 Upper longitudinal structural members in the cargo hold region of container carriers include the topmost strakes, the sheer strake, upper deck, coaming plate, coaming top plate, and all attached longitudinal stiffeners of the inner and outer hull (bulkhead) (see Figure 5.2.1).

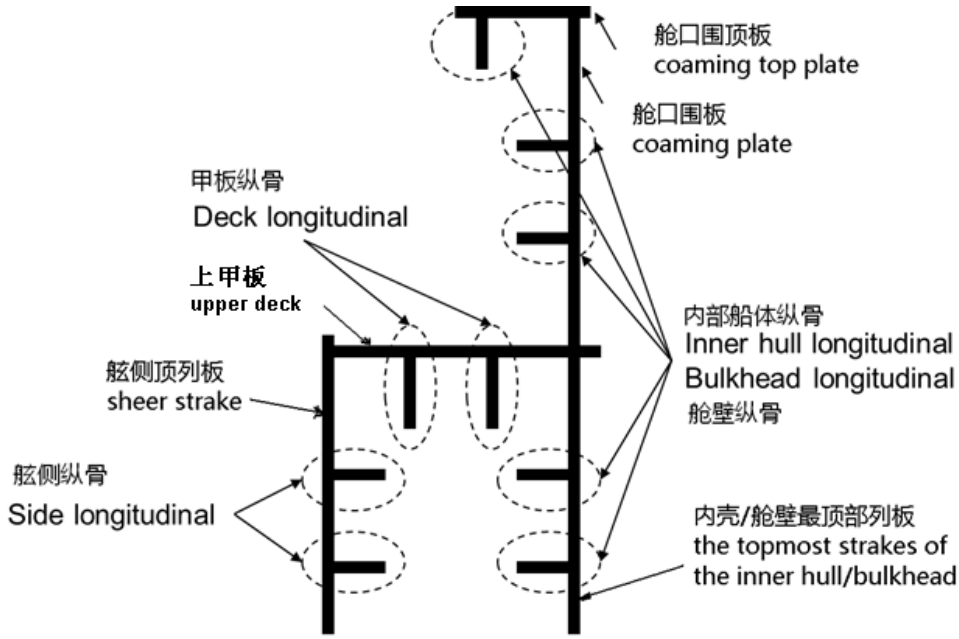


Figure 5.2.1 Longitudinal Structure in the Cargo Hold Region of Container Carriers

5.2.2 Where higher strength steel plates with thickness over 50 mm but not exceeding 100 mm are used for upper deck longitudinal structure (upper deck plating, hatch side coaming and hatch coaming top ~~plate, coaming plate and all attached longitudinals~~) of container carriers, steel plates with toughness not lower than grade E are to be adopted. Proper measures for prevention of brittle crack initiation and propagation are to be taken in accordance with the provisions given in Table 5.2.2, as appropriate.

Safety Measures for Extremely Thick Steel Plates **Table 5.2.2**

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.
	$85 < t \leq 100$	A	X	N.A.	X	X
		B	X①	N.A.②	N.A.	X
460 (FCAW)	$50 < t \leq 100$	A	X	N.A.	X	X
		B	X①	N.A.②	N.A.	X
460 (EGW)	$50 < t \leq 100$	-	X	N.A.	X	X

Measures:
1 (During construction) NDT other than visual examination on all target block joints: see 5.5.
2 (After delivery) NDT other than visual examination on all target block joints: see 5.6.
3 (During construction) Brittle crack arrest design against straight propagation of brittle crack along weldline to be taken: see 5.3.7(2)a, b or c.
4 (During construction) Brittle crack arrest design against deviation of brittle crack from weldline: see 5.3.7(1)a.
5 (During construction) Brittle crack arrest design against propagation of cracks from other weld areas such as fillets and attachment welds: see 5.3.7(1)a.

Notes:
1. The thickness and the yield strength shown in the table apply to the hatch coaming ~~structure~~top plating and side plating, and are the controlling parameters for the application of countermeasures. If the as-built thickness of the hatch coaming top plating and side plating ~~structure~~ is below the values contained in the table, countermeasures are not necessary regardless of the thickness and yield strength of the upper deck.
2. "X" means "To be applied"; "N.A." means "Need not to be applied"; selectable from option "A" and "B".
3. FCAW means flux cored arc welding.
4. EGW means electrogas welding.
① See 5.3.7 (2) d of this Chapter.
② See 5.6.1 (3).

5.2.3 For steel plates with thickness exceeding 100 mm, appropriate measures for prevention of brittle crack initiation and propagation are to be taken by CCS in accordance with the provisions of the Guidelines, as appropriate.

5.2.4 Notwithstanding the provisions of this Chapter are mainly for block-to-block butt joints in the upper structure of container carriers, appropriate preventive measures are to be considered for brittle crack initiation and propagation of base metal away from such joints in accordance with 5.3.6(2).

5.3 Application of higher strength steel design

5.3.1 The application of higher strength steel design is to comply with the requirements for assessment of hull girder strength and fatigue strength and crack arrest design and relevant requirements for NDT.

5.3.2 Material factor K of higher strength steels for the assessment of hull girder strength is to be taken in accordance with the strength grade of materials as given in Table 5.3.2.

Material Factor *K* of Higher Strength Steels **Table 5.3.2**

Material strength, in N/mm^2	355	390	460
Material factor	0.72	0.68	0.62

5.3.3 Where higher strength steel is used for hull structure, the assessment of longitudinal strength (yield, buckling) and fatigue strength is to be carried out in accordance with the relevant provisions of PART TWO of CCS Rules for Classification of Sea-going Steel Ships. For the

fatigue strength assessment of H47 steels, very fine mesh is to be used to calculate the hot spot stresses and the finite element model is to be submitted to CCS for review together with calculation report.

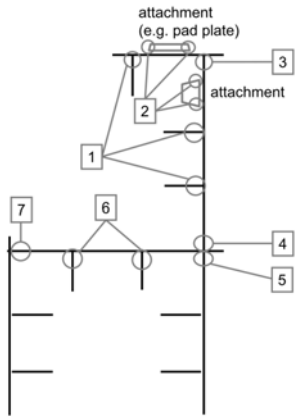
5.3.4 Special consideration is to be paid to the details of connections of structural members where higher strength steels with specified minimum yield strength not less than 460 N/mm^2 are applied to connections between outfitting and hull structures. Such connections are to be carried out in accordance with the relevant provisions of CCS.

5.3.5 Measures for prevention of brittle crack propagation, which is the same meaning as brittle crack arrest design, are to be taken within the cargo hold region of container carriers where extremely thick higher strength steel plates are used. The approach given in this section generally applies to the block-to-block joints but it should be noted that cracks can initiate and propagate away from such joints. Therefore, appropriate measures should be considered in accordance with 5.3.6 (2).

5.3.6 The purpose of the brittle crack arrest design is aimed at arresting propagation of a crack at a proper position and to prevent large scale fracture of the hull girder. In consideration of prevention of brittle crack, the point of a brittle crack initiation is to be considered in the block-to-block butt joints both of coaming plate and upper deck. Both of the following cases are to be considered with regard to propagation from the point of a brittle crack initiation:

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

(2) where the brittle crack initiates in the butt joint but deviates away from the butt joint weld and runs into base metal, or where the brittle crack initiates from any other weld (see the Figure 5.3.6(2) below for definition of other welds) and propagates into the plate.



"Other weld areas" includes the following:

1) Fillet welds where hatch side coaming plating, including top plating, meet longitudinals;

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

3) Fillet welds where hatch side coaming top plating meet hatch side coaming plating;

4) Fillet welds where hatch side coaming plating meet upper deck plating;

5) Fillet welds where upper deck plating meet inner hull/bulkheads;

6) Fillet welds where upper deck plating meet longitudinal; and

7) Fillet welds where sheer strakes meet upper deck plating.

Figure 5.3.6(2) Other weld Areas

5.3.7 The following are considered to be acceptable examples of brittle crack arrest-design. The detail design arrangements are to be submitted to CCS for approval. Other concept designs may be considered and accepted for review by CCS.

(1) Brittle crack arrest design for 5.3.6(2):

a. Brittle crack arresting steel with properties specified in Chapter 4 of the Guidelines is to be used for the upper deck 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 5.3.6(1):

a. 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.

b. 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.

c. 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.

d. The application of enhanced NDT particularly time of flight diffraction (TOFD) technique using stricter defect acceptance in lieu of UT technique specified in 5.5 can be an alternative to (a), (b) and (c) of this subparagraph.

5.4 Construction and welding of higher strength steels

5.4.1 In addition to the provisions of this Chapter, the assembling and welding of higher strength hull structural steels are to comply with the relevant provisions of Chapter 5, PART THREE of CCS Rules for Materials and Welding.

5.4.2 The free edges of longitudinal structure members of hatch coamings of container carriers are to be smooth, and they are preferably processed by machining. The coaming top plates are to be free from any notch and its corners may be rounded by machining. The radius generally need not be greater than 5 mm.

5.4.3 The welding procedure test and approval range of H47 steels may be referred to relevant provisions for steels with minimum yield strength of 390 N/mm^2 of Chapter 3, PART THREE of CCS Rules for Materials and Welding. Test results are to comply with following provisions:

(1) Transverse tensile strength is to be not less than 570 N/mm^2; Vickers hardness of surface and center is to be not more than 380 HV10.

(2) For the impact energy in the approval test of crack arrest steel welding procedures, the requirement for a minimum of 64J at -20℃ is to be satisfied.

(3) In addition to general mechanical tests for weld joints of crack arrest steels of all grades,

full-thickness specimens are to be taken for CTOD tests for weld center and fusion line. Test results are to be reported.

5.4.4 In addition to the provisions of Chapter 2, PART THREE of CCS Rules for Materials and Welding, welding consumables for higher strength steels are to comply with the following provisions:

(1) Welding consumables for H47 steels are as shown in Table 5.4.4.

Recommended Welding Consumables for H47 Steels **Table 5.4.4**

Welding consumables	Base metal with thickness less than 50 mm	Base metal with thickness of 50~100 mm
3Y46	AH47, DH47	AH47
4Y46	AH47, DH47, EH47	AH47, DH47
5Y46	AH47, DH47, EH47, FH47	AH47, DH47, EH47
Subject to special consideration	AH47, DH47, EH47, FH47	AH47, DH47, EH47, FH47

(2) For welding consumables used for hatch coamings of container carriers, the requirement for diffusible hydrogen content in deposited metal less than 5 ml/100 g is to be satisfied.

5.4.5 The welding of extremely thick higher strength steel plates for container carriers is to be carried out by the welders passing the qualification tests specified in CCS rules or acceptable standards, using approved consumables in accordance with approved welding procedures and the following requirements:

(1) 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) Preheating is to be 50℃ or over when air temperature is 5℃ or below. In the case where P_{cm} is less than or equal to 0.19 and air temperature is 0℃ or below, special consideration may be given by CCS.

(3) Special care is to be paid to the final welds so that harmful defects do not remain and transition of surface is smooth. Jig mountings are to be completely removed with no defects left. The surface treated may be examined by non-destructive testing if necessary.

5.5 Non-destructive testing (NDT) during construction

5.5.1 Where measure No.1 (i.e. NDT during construction) is required in accordance with Table 5.2.2, visual examination and ultrasonic testing (UT) are to be carried out on all block-to-block butt welds of upper longitudinal structural members in the cargo hold region in accordance with the inspection procedure requirements of Chapter 7 of CCS Guidelines for Inspection of Hull Welds.

5.5.2 Visual examination is to comply with the requirements of level B of ISO 5817 or other equivalent standards.

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

5.5.4 The acceptance criteria may be adjusted under consideration of the appertaining brittle crack initiation prevention procedure and where this is more severe than that found in 5.5.3, the UT procedure is to be amended accordingly to a more severe sensitivity.

5.5.5 A set of copies of testing reports is to be maintained on board for verification in random examination of special survey.

5.6 Periodic NDT after delivery

5.6.1 Where measure No.2 (i.e. NDT after delivery) is required in accordance with Table 5.2.2, the following tests are to be carried out in accordance with the relevant requirements of Chapter 7 of CCS Guidelines for Inspection of Hull Welds in each special survey:

(1) For discontinuities found in last NDT, an overall re-testing is to be carried out for verification of no propagation of the discontinuities at these locations.

(2) For block-to-block butt welds of hatch side coamings, coaming top plates and strength deck, 10% of the length is to be selected randomly for UT.

(3) For butt welds of longitudinal structure of hatch side coamings other than those specified in (2), not more than 5% of the length is to be selected randomly for UT, as appropriate.

5.6.2 Testing results are to comply with the requirements of 5.5.3 of this Chapter. Where any sign of propagation of defects is found, records are to be made and reported to CCS. The location is to be re-inspected at least once a year and to be repaired in time as necessary.

Appendix A Standard ESSO Test

A1 Scope

The ESSO test method is used to estimate the brittle crack arrest toughness value K_{ca} of rolled steel plates for hull of thickness 100 mm or less.

A2 Symbols

Table A1 Symbols Used and Their Meanings

Symbol	Unit	Meaning
t_S	mm	Thickness of specimen
W_S	mm	Width of specimen
L_S	mm	Length of specimen
t_r	mm	Thickness of tab plate
W_r	mm	Width of tab plate
L_r	mm	Length of tab plate
L_P	mm	Distance between pins
a	mm	Length of crack projected on surface normal to the line of load
a_a	mm	Maximum crack length at brittle crack arrest position
T	℃	Temperature of test specimen
dT/da	℃/mm	Temperature gradient of test specimen
σ	N/mm^2	Gross stress in tested part ($load/W_S.t_S$)
K_{ca}	N/mm$^{3/2}$	Brittle crack arrest toughness value

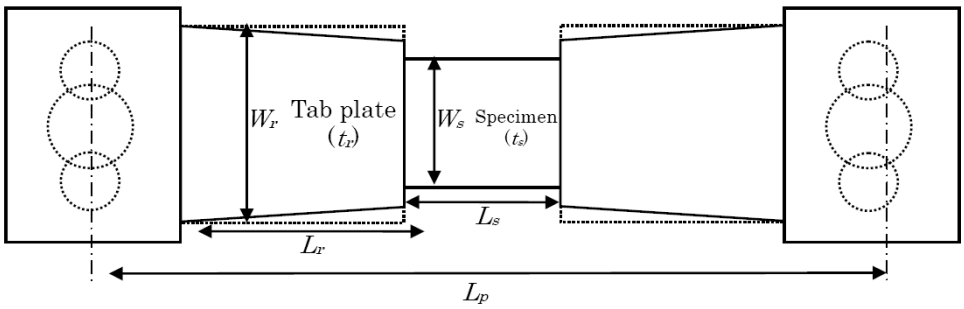


Figure A1 Conceptual View of Test Specimen, Tab and Load Jig

A3 Purpose

A3.1 The purpose of this test is to encourage the performance of a standard test for assessment of brittle crack arrest toughness with temperature gradient and to obtain the corresponding brittle crack arrest toughness value K_{ca}.

A4 Standard test specimen

A4.1 Figure A2 shows the shape and size of the standard test specimen.

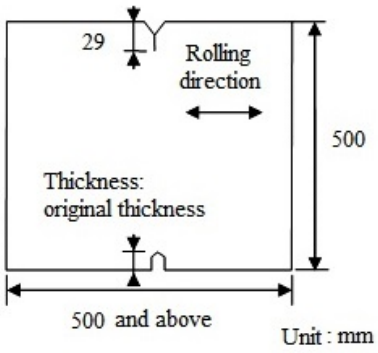


Figure A2 Shape and Size of Specimen

A4.2 The thickness and width of the test specimen are to be in accordance with Table A2.

Table A2 Thickness and Width of Test Specimen

Thickness, t_s	100 mm and below
Width of specimen, W_s	500 mm

Note: If the width of the test specimen cannot be made at 500 mm, it may be taken as 600 mm.

A4.3 The test specimens are to be taken from the same steel plate.

A4.4 Test specimens are to be taken in such a way that axial direction of the load is parallel to the rolling direction of the steel plate.

A4.5 The thickness of the test specimen is to be taken the same as the thickness of the steel plate to be used in the vessel structure.

A5 Test equipment

A5.1 The test equipment to be used in to consist of pin load type hydraulic test equipment capable of tensile tests.

A5.2 The distance between the pins is to be not less than 2,000 mm. The distance between pins refers to the distance between the centers of the pin diameters.

A5.3 Drop weight type or air gun type impact equipment may be used for the impact energy required for generating brittle cracks.

A5.4 The wedge is to have an angle greater than the upper notch of the test specimen, and an opening force is to be applied on the notch.

A6 Test preparations

A6.1 The test piece is to be fixed directly to the pin load jig or by means of weld joint through the tab plate. The overall length of the test specimen and tab plate is to be not less than $3W_s$. The thickness and width of the tab plate are to be in accordance with Table A3.

Table A3 Allowable Dimensions of Tab Plate

	Thickness	Width
Dimensions of tab plate	$0.8t_s$ [(1)] $\le t_r \le 1.5t_s$	$W_s \le W_r \le 2W_s$

Note 1: If the tab plate has a thickness smaller than the test specimen, the reflection of stress wave will be on the safer side for the assessment; therefore, considering the actual circumstances for conducting the test, the lower limit of thickness is taken as $0.8t_s$.

A6.2 Thermocouples are to be fitted at 50 mm pitch on the notch extension line of the test specimen.

A6.3 If the brittle crack is estimated to deviate from its presumed course, thermocouples are to

be fitted at two points separated by 100 mm on the line of load from the notch extension line at the center of width of the test specimen.

A6.4 If dynamic measurements are necessary, strain gauges and crack gauges are to be fitted at specific locations.

A6.5 The test specimen is to be fixed to the testing machine together with the tab plate after welding and the pin load jig.

A6.6 The impact equipment is to be mounted. The construction of the impact equipment is to be such that the impact energy is correctly transmitted. An appropriate jig is to be arranged to minimize the effect of bending load due to the impact equipment.

A7 Test method

A7.1 To eliminate the effect of residual stress or correct the angular deformation of tab welding, a preload less than the test load may be applied before cooling.

A7.2 Cooling and heating may be implemented from one side on the side opposite the side on which the thermocouple is fitted, or from both sides.

A7.3 The temperature gradient is to be controlled in the range of 0.25℃/mm to 0.35℃/mm in the range of width from $0.3W_s$ to $0.7W_s$ at the central part of the test specimen.

A7.4 When the specific temperature gradient is reached, the temperature is to be maintained for more than 10 min, after which the specified test load may then be applied.

A7.5 After maintaining the test load for at least 30 seconds, a brittle crack is to be generated by impact. The standard impact energy is taken as 20 to 60 J per 1 mm plate thickness. If the brittle crack initiation characteristics of the base metal are high, and it is difficult to generate a brittle crack, the impact energy may be increased to the upper limit of 120 J per 1 mm plate thickness.

A7.6 Loading is stopped when the initiation, propagation, and arrest of crack have been confirmed. Normal temperature is restored, and if necessary, the ligament is broken by gas cutting and forcibly the specimen is broken by using the testing machine. Or, after the ductile crack has been propagated to an adequate length with the testing machine, the ligament is broken by gas cutting.

A7.7 After forcing the fracture, photos of the fractured surface and the propagation route are to be taken, and the crack length is to be measured.

A8 Test results

A8.1 The distance from the top of the test specimen including the notch to the maximum length in the plate thickness direction of the arrested crack tip is to be measured. If the crack surface deviates from the surface normal to the line of load of the test specimen, the projected length on the surface normal to the line of load is to be measured. In this case, if the trace of brittle crack arrest is clearly visible on the fractured surface, the first crack arrest position is taken as the arrest crack position.

A8.2 From the results of thermocouple measurement, the temperature distribution curve is plotted, and the arrest crack temperature is measured corresponding to the arrest crack length.

A8.3 The brittle crack arrest toughness value (K_{ca} value) of each test is to be determined by using the following formula:

$$K_{ca} = \sigma\sqrt{\pi a}\sqrt{\left(\frac{2W_S}{\pi a}\right)\tan(\pi a / 2W_S)}$$

A9 Report

A9.1 The following items are to be reported:

(a) Test materials: designation grade, cast or plate number, specifications;

(b) Testing machine specifications: testing machine capacity, distance between pins (L_p);

(c) Load jig dimensions: tab plate thickness (t_r), tab plate width (W_r), test specimen length including tab plate ($L_s + 2L_r$);

(d) Test specimen dimensions: plate thickness (t_s); test specimen width (W_s) and length (L_s);

(e) Test conditions: preload stress, test stress, temperature distribution (figure or table), impact energy;

(f) Test results: crack arrest length (a_a), temperature gradient at arrest position, brittle crack arrest toughness (K_{ca});

(g) Dynamic measurement results (if measurement is carried out): crack growth rate, strain change;

(h) Test specimen photos; fracture route, fractured surface.

A9.2 If the conditions below are not satisfied, the test results are to be treated as reference values.

(i) The brittle crack arrest position is to be in the range of the hatched part shown in Figure A3. In this case, if the brittle crack arrest position is more than 50 mm away from the center of the test specimen in the longitudinal direction of the test specimen, the temperature of the thermocouple at the ±100 mm position is to be within ±3℃ of the thermocouple at the center.

(ii) The brittle crack has no distinct crack bifurcation while it propagates.

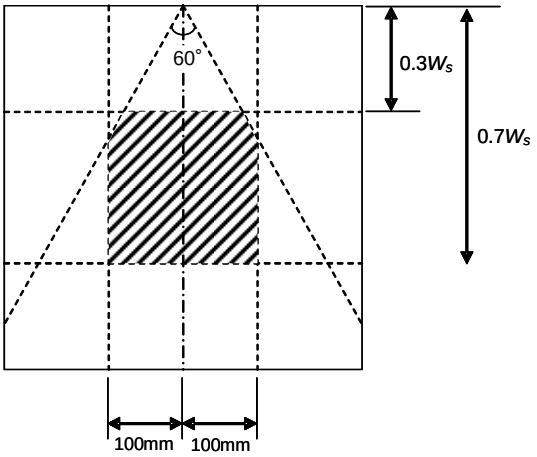


Figure A3 Necessary Conditions of Arrest Crack Position

A9.3 From effective test results measured at more than 3 points, the linear approximation equation is to be determined on the Arrhenius plot, and K_{ca} at the desired temperature is to be calculated. In this case, data should exist on both sides, that is, the high temperature and low temperature sides around the assessed temperature.

Appendix B Standard Double Tension Test

B1 Scope

This test method is used to measure crack arrest temperature T_k and brittle crack arrest toughness K_{ca} of higher strength steel plates with thickness not more than 100 mm for ships.

B2 Principle

The principle of this test is to measure crack arrest temperature and brittle crack arrest toughness of steels by studying the propagation and termination of moving cracks at the main tensile plate under certain stress and temperature gradient.

B3 Purpose

The purpose of this test is to encourage the performance of a standard test for assessment of brittle crack arrest toughness with temperature gradient and to obtain the corresponding brittle crack arrest temperature T_k and brittle crack arrest toughness value K_{ca}.

B4 Symbols

Symbols used in this method and their meanings are shown in Table B1 and Figure B1.

Table B1 Symbols Used and Their Meanings

Symbol	Unit	Meaning
t_s	mm	Thickness of test specimen
W_s	mm	Width of main tensile plate of test specimen
L_s	mm	Length of test specimen
t_r	mm	Thickness of tab plate
W_r	mm	Width of tab plate
L_r	mm	Length of tab plate
L_p	mm	Distance between pins
a	mm	Crack arrest length
T	℃	Test temperature
dT/da	℃/mm	Temperature gradient of test specimen
σ	N/mm^2	Main tensile stress (load/ $W_s \cdot t_s$)
T_k	℃	Crack arrest temperature
K_{ca}	N/mm$^{3/2}$	Brittle crack arrest toughness

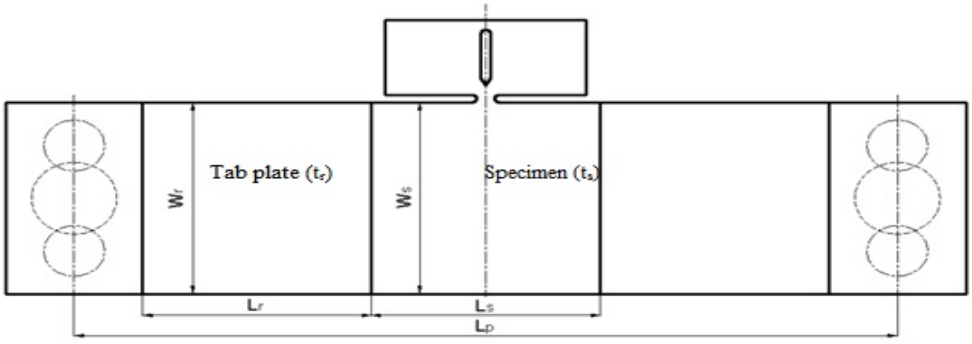


Figure B1 Specimen and Tab Plate

B5 Test specimen

B5.1 Test specimen consists of crack initiation plate and main tensile plate. The type and size are shown in Figure B2.

B5.2 Thickness of test specimen and width of main tensile plate are shown in Table B2.

Table B2 Thickness of Test Specimen and Width of Main Tensile Plate

Thickness, t_s	≤100 mm
Width[(1)], W_s	500 mm

Note 1: The width of main tensile plate may be taken as 600 mm. Increasing the width of crack initiation plate is to be considered in actual preparation of test specimen.

B5.3 The same batch of test specimens are to be taken from the same steel plate. Test specimens are to be taken in such a way that the length direction is parallel to the rolling direction of the steel plate.

B5.4 The sharp notch of crack initiation plate may be prepared by wire-cutting or pressing.

B5.5 The test piece is to be fixed directly to the pin load jig or by means of weld joint through the tab plate. The overall length of the test specimen and tab plate is to be not less than $3W_s$. The thickness and width of the tab plate are to be in accordance with Table B3.

Table B3 Allowable Dimensions of Tab Plate

Dimensions of tab plate	Thickness	Width
	$0.8t_s$[(1)] $\le t_r \le 1.5t_s$	$W_s \le W_r \le 2W_s$

Note 1: If the tab plate has a thickness smaller than the test specimen, the reflection of stress wave will be on the safer side for the assessment; therefore, considering the actual circumstances for conducting the test, the lower limit of thickness is taken as $0.8t_s$.

B6 Establishment of temperature field

B6.1 The notch of crack initiation plate of test specimen is cooled to a low temperature.

B6.2 A gradient temperature field is established at the main tensile plate and the temperature gradient at the center line of width from $0.3W_s$ to $0.7W_s$ is to remain in the range of 0.25℃/mm ~ 0.35℃/mm.

B7 Testing machine

B7.1 Horizontal or vertical type tension testing machine may be used in double tension crack arrest test. The load of testing machine is to be applied steady and free from impact and vibration.

B7.2 The applied load of testing machine is to be maintained for not less than 30 seconds. The fluctuation range of applied load within 30 seconds is to be less than 5% of the maximum load of the testing machine.

B7.3 When testing machine is loaded, the line between forward and backward (or upper and lower) pins of the test specimen is to coincide with the axis of tensile load. The deviation (if any) is not to exceed 15 mm.

B7.4 Distance between pins is to be not less than 2,000 mm.

B8 Test procedure

B8.1 The test specimen is welded with tab plate.

B8.2 Thermocouples are fitted at 50 mm pitch on the center line of width on the surface of specimen. If the propagation path of brittle crack is anticipated to deviate, thermocouples are to be fitted at the location 100 mm from the center line with the same pitch.

B8.3 The integral of welded test specimen and tab plate is lifted to the testing machine and the main and auxiliary tension devices are installed.

B8.4 The crack initiation plate notch of test specimen is cooled.

B8.5 The temperature gradient reaches the required level, and is to be maintained for at least 10 min.

B8.6 The applied main tensile load to the test specimen is to be maintained for not less than 30 seconds, then the auxiliary tension device is started till crack initiates in the test piece.

B8.7 The auxiliary tension device and main tensile device are unloaded after the initiation, propagation in the test piece, and arrest of crack have taken place.

B8.8 The auxiliary tension device is removed and test specimen is reloaded till it fractures.

B8.9 Test specimen is removed from the testing machine.

B8.10 The crack arrest length at the center of main tensile plate is measured after fracture.

B9 Test results

B9.1 Crack arrest length a is the distance from the edge of main tensile plate adjacent to crack initiation plate to the crack arrest position at the center.

B9.2 The curve of relations between the temperature measured by thermocouple at the main tensile plate and the location of thermocouple is plotted. The temperature of the crack arrest position (i.e. crack arrest temperature T_k) may be determined by interpolation.

B9.3 The main tensile stress σ is determined by main tensile load and the width and thickness of test specimen.

B9.4 The brittle crack arrest toughness K_{ca} is determined by using the following formula:

$$K_{ca} = \sigma\sqrt{\pi a} \cdot \sqrt{\left(\frac{2W_s}{\pi a}\right)\tan\left(\frac{\pi a}{2W_s}\right)}$$

B10 Report

B10.1 The report is to include:

(a) Test materials: designation grade, cast or plate number, specifications;

(b) Testing machine specifications: testing machine capacity, distance between pins (L_p);

(c) Load jig dimensions: tab plate thickness (t_r), tab plate width (W_r), test specimen length including tab plate ($L_s + 2L_r$);

(d) Test specimen dimensions: plate thickness (t_s); test specimen width (W_s) and length (L_s);

(e) Test conditions: main tensile stress, temperature distribution (figure or table);

(f) Test results: crack arrest length (a_a), temperature gradient at arrest position (T_k), brittle crack arrest toughness (K_{ca});

(g) Dynamic measurement results (if measurement is carried out): crack growth rate, strain change;

(h) Test specimen photos; fracture route, fractured surface.

B10.2 For test results, the conditions below are to be satisfied:

(1) The brittle crack arrest position is to be in the range of the hatched part shown in Figure B3.

(2) The brittle crack is to have no distinct crack

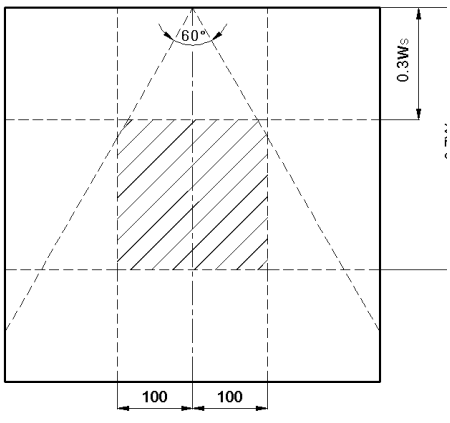


Figure B3
Effective Crack Arrest Zone

bifurcation while it propagates.

If the conditions above are not satisfied, the test results are only to be treated as reference values.

B10.3 From effective test results measured at more than 3 points, the linear approximation equation is to be determined on the Arrhenius plot, and K_{ca} at the desired temperature and crack arrest temperature T_k under the desired allowable stress are to be calculated. In this case, data should exist on both sides, that is, the high temperature and low temperature sides around the assessed temperature.

Appendix C Specimens for H47 Steel Approval Test

	Test	Direction of specimen	Sampling position	Number	Remark
Mechanical properties test of base metal	Chemical composition analysis		Ladle sample, top and bottom	One for each position	
	Tension test	Longitudinal, transverse	Top and bottom	One for each position	
	Bend test	Longitudinal, transverse	Top and bottom	One for each position	
	Charpy impact test	Longitudinal specimen (top and bottom)	1/4 of thickness Mid of thickness (for thickness greater than 40 mm)	One set of three specimens at each position	At least four groups of tests are to be carried out, not less than two groups are carried out at the temperature lower than the impact test temperature of applied steel grade. In addition to the determination of the energy value, the lateral expansion and the percentage crystallinity are also to be reported, and a curve is to be drawn to determine the nil-ductility transition temperature (corresponding to 50% crystallinity). The photo of the fracture is to be provided
		Transverse specimen (top and bottom)	1/4 of thickness Mid of thickness (for thickness greater than 40 mm)		
	Strain ageing Charpy impact test	Longitudinal specimen (top)	1/4 of thickness Mid of thickness (for thickness greater than 40 mm)	One set of three specimens at each position	5% deformation before test, and then heated to 250℃ for 1 h. The temperature of impact test is in accordance with the tested material grade
	Brittle crack initiation test	Transverse specimen	1/4 of thickness (full thickness insofar as possible)	Deep notch test or CTOD test	The CTOD test method is referred to Section 8, Chapter 2 of PART ONE of Rules for Materials and Welding. Test results are reported
	Drop weight test	Transverse	One end		Test method is referred to Section 10, Chapter 2 of PART ONE of Rules for Materials and Welding. Nil-ductility test temperature is determined and reported
	Brittle crack arrest test		One end		ESSO test or double tension test. Refer to Appendix A or Appendix B of the Guidelines
Metallographic examination of base metal	Sulphur print test		Billet and finished product		The top of ingot is selected. For continuous casting, samples may be taken randomly
	Macrostructure examination		One end		
	Microscopic examination		Two ends		
Welding properties test of base metal	Joint transverse tension test	Transverse	Full thickness		Equally spaced laminated sampling is allowable. An average value is calculated after testing
	Charpy V-notch impact test	Longitudinal specimen	1/4 of thickness Root of weld		Four groups which notch respectively at the position of 2 mm, 5 mm and 20 mm from fusion line and heat affected zone, not less than two groups are carried out at the temperature lower than the impact test temperature of applied steel grade
	Inclined Y-shape weld crack test	Transverse	Full thickness		Recommended pre-heating temperature is reported
	Brittle crack initiation test	Longitudinal specimen	1/4 of thickness		The thickness of specimen is 50 mm. The CTOD values at fusion line and at the position of 2 mm from fusion line are measured