Brittle Crack Arrest Properties

Amended Guidance

Guidance for the Survey and Construction of Steel Ships Part K
Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use

Reason for Amendment

IACS Unified Requirement (UR) W31 stipulates requirements related to the specification values for YP47 steel plates (steel plates with a specified minimum yield point of 460 N/mm^2) and steel plates with brittle crack arresting properties (hereinafter referred to as "arrest steel") and approval for its manufacturing procedures. ClassNK has already incorporated the UR into Part K of its Rules for Survey and Construction of Steel Ships and its Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use.

In general, the arrest properties required for arrest steel are confirmed by large-scale arrest tests (temperature gradient ESSO tests, double tension tests, crack arrest temperature (CAT) evaluation tests, etc.), but since such tests tend to be rather labor intensive, alternative methods of evaluation have been permitted for the production testing of steel plates. However, the approval procedures for such evaluation methods have up until now been left to the individual judgment of each classification society.

Therefore, IACS discussed a unified procedure for the approval of alternative tests and defined the requirements for approval using the results of small-scale tests by confirming the correlation between the results of large-scale arrest tests and those of small-scale tests. In addition, based on an operational performance of the requirements for the approval of arrest steel plates, requirements for approval procedures were reviewed and adopted by IACS as UR W31(Rev. 3) in March 2023.

Accordingly, relevant requirements are amended based on IACS UR W31(Rev.3).

Outline of Amendment

The main contents of this amendment are as follows:

(1) Amends requirements related to the extent of approval for YP47 with respect to manufacturer approval.
(2) Amends the guidance for temperature gradient ESSO tests and double tension tests to refer to ISO 20064:2019.
(3) Specifies the approval scheme for the small-scale test methods for brittle crack arrest steels as Annex 1.1, Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use.

"Guidance for the survey and construction of steel ships" has been partly amended as follows:

Part K MATERIALS

K3 ROLLED STEELS

K3.12 Additional Requirements for Brittle Crack Arrest Properties

K3.12.3 has been amended as follows.

K3.12.3 Brittle Crack Arrest Properties etc.

1 In **3.12.3-1, Part K of the Rules**, "the discretion of the Society" ~~can be regarded as~~ means that carrying out the test in accordance with **Annex K3.12.3-1** "~~GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS~~ Guidance for Temperature Gradient ESSO Tests and Double Tension Tests" in the case of temperature gradient *ESSO* tests and double tension tests. The number of test specimens selected from a single test sample may be in accordance with ~~the requirements in~~ **3.12.5-1, Part K of the Rules**, notwithstanding ~~the requirements in~~ **1.2.11, Annex K3.12.3-1**.

2 In **3.12.3-2, Part K of the Rules**, "the discretion of the Society" ~~may be regarded as~~ means that carrying out the test in accordance with **Annex K3.12.3-2** "~~GUIDANCE FOR CAT EVALUATION TESTS~~ Guidance for CAT Evaluation Tests" in the case of Crack Arrest Temperature (*CAT*) evaluation tests.

3 For **3.12.3-1**, **3.12.3-2** and **3.12.5-4, Part K of the Rules**, test plans, containing information on the items mentioned below, are to be submitted to the Society for approval ~~of the Society.~~

(1) Testing machine specifications (including testing machine capacity and distance between pins)
(2) Details of test specimen (including types and dimensions of test specimen and method of joint with tab plate)
(3) Types, dimensions and mechanical properties of tab plate and load jig
(4) Measurement specifications (including whether dynamic measurements are necessary and positions on which the thermocouples, strain gauges and crack gauges are fitted)
(5) Test conditions (including how to generate a brittle crack, impact energy, temperature of test specimen, temperature gradient, preload stress and test stress)

4 In **3.12.3-3, Part K of the Rules**, "A brittle fracture test deemed appropriate by the Society" means a test with an evaluation procedure approved by the Society in accordance with **Annex 1.1** "Approval Scheme of Small-scale Test Methods for Brittle Crack Arrest Steels", **Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use**.

Annex K3.12.3-1 has been amended as follows.

Annex K3.12.3-1 GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS

1.1 ~~General~~ Application

~~**1.1.1 Application**~~

1 *ISO* 20064:2019 specifies a test method for the determination of brittle crack arrest toughness of steel by using wide plates with a temperature gradient. This annex specifies the test procedures for brittle crack arrest toughness (i.e. K_{ca}) of steel using a fracture mechanics parameter and determination method for K_{ca} at the specific temperatures specified in *ISO* 20064:2019. Additionally, this annex specifies the evaluation method for K_{ca} of test plate.

2 ~~The requirements in this Guidance~~ This annex apply to rolled steel plates with thicknesses ~~of~~ exceeding 50 *mm* but 100 *mm* or less. Rolled steel plates having thicknesses exceeding 100 *mm* are ~~to~~ at the discretion of the ~~s~~Society.

~~**1.1.2 Definition**~~

~~Unless specified otherwise, the definition of the symbols used in this Guidance are as specified in **Table 1.**~~

~~Table 1 Definition of the Symbols Used in this Guidance~~

~~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 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 value~~
~~L~~	~~*mm*~~	~~Test specimen length~~
~~L_{lp}~~	~~*mm*~~	~~Distance between loading pins~~
~~L_{pc}~~	~~*mm*~~	~~Pin chuck length~~
~~L_{tb}~~	~~*mm*~~	~~Tab plate length~~
~~T~~	~~°C~~	~~Temperature or arrest temperature~~
~~T_D~~	~~*K*~~	~~Specific temperature~~
~~T_K~~	~~*K*~~	~~Arrest temperature of arrest toughness value obtained from requirement 1.2.9~~
~~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 main crack tip in width direction~~
~~x_{ba}~~	~~mm~~	~~Coordinate of longest branch crack tip in width direction~~
~~y_a~~	~~mm~~	~~Coordinate of main crack tip in stress loading direction~~
~~y_{ba}~~	~~mm~~	~~Coordinate of longest branch crack tip in stress loading direction~~
~~σ~~	~~N/mm^2~~	~~Applied stress~~
~~σ_{y0}~~	~~N/mm^2~~	~~Yield stress at room temperature~~

1.2 ~~Temperature Gradient *ESSO* Tests~~ Test Procedures

~~1.2.1 General~~

1 ~~The requirements in this section are related to the evaluation of brittle crack arrest toughness through the use of temperature gradient *ESSO* tests.~~ Test procedures (including testing equipment, test specimens, test methods, determination of arrest toughness, reporting of test results, etc.) are to be in accordance with *ISO* 20064:2019.

2 ~~Items not specified in this Guidance are to be in accordance with *WES2815* (Test method for brittle crack arrest toughness, K_{ca}) of the Japan Welding Engineering Society.~~ As a method for initiating a brittle crack, a secondary loading mechanism can be used in accordance with Annex D of *ISO* 20064:2019, except that the first sentence in Annex B.2.4 of *ISO* 20064:2019 is to be read as "Obtain the value {Kca /[K0 *exp(−c/TcaK)]} for each data point".

~~1.2.2 Test Equipment~~

~~**1** Test equipment is to be hydraulic test equipment of a pin load type which is capable of tensile tests.~~

~~**2** The method of applying loads is to be such that the stress distribution in the plate width direction is made uniform by aligning the centers of the loading pins of both sides and neutral axis of the integrated specimen.~~

~~**3** The direction of loading is to be either vertical or horizontal. In the case of the horizontal direction, test specimen surfaces are to be placed perpendicular to the ground.~~

~~**4** The distance between the loading pins, L_p, is to be standardized as 3.4 W or more.~~

~~1.2.3 Impact Equipment~~

~~**1** Impact equipment for initiating brittle crack in integrated specimen is to be of either a drop weight type or an air gun type. Impact load is to be applied to integrated specimen by wedge.~~

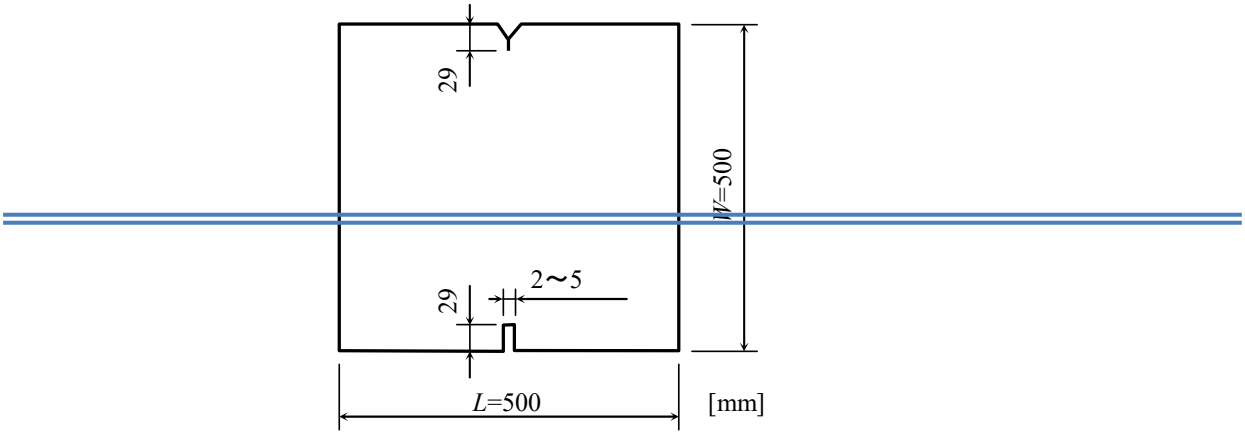
~~**2** Wedge is to be hard enough to prevent significant plastic deformation caused by impact.~~

~~**3** The thickness of a wedge thickness is to be equal to or greater than that of the test specimen. In addition, the angle of the wedge is to be greater than the angle of the notch formed in the test specimen and have a shape capable of opening up the notch of the test specimen.~~

~~1.2.4 Test Specimen Shapes~~

~~**1** The standard test specimen shape is shown in **Fig. 1**. In principle, test specimen length, L, is to be equal to or greater than test specimen width, W.~~

Fig. 1　Standard Test Specimen Shape



2　Table 2 shows the ranges of test specimen thicknesses, *t*, and widths, *W*.

Table 2　Dimensions of Test Specimens

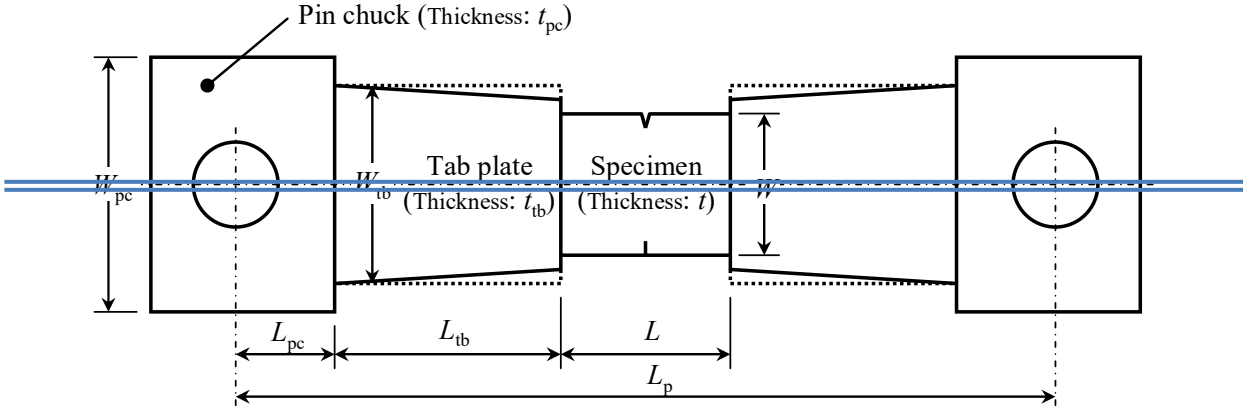
Test specimen thickness, *t*	50 *mm* < *t* ≤ 100 *mm*
Test specimen width, *W*	350 *mm* ≤ *W* ≤ 1000 *mm*
Test specimen width/test specimen thickness, *W* / *t*	*W* / *t* ≥ 5

Note:
Test specimen width is standardized as 500 *mm*.

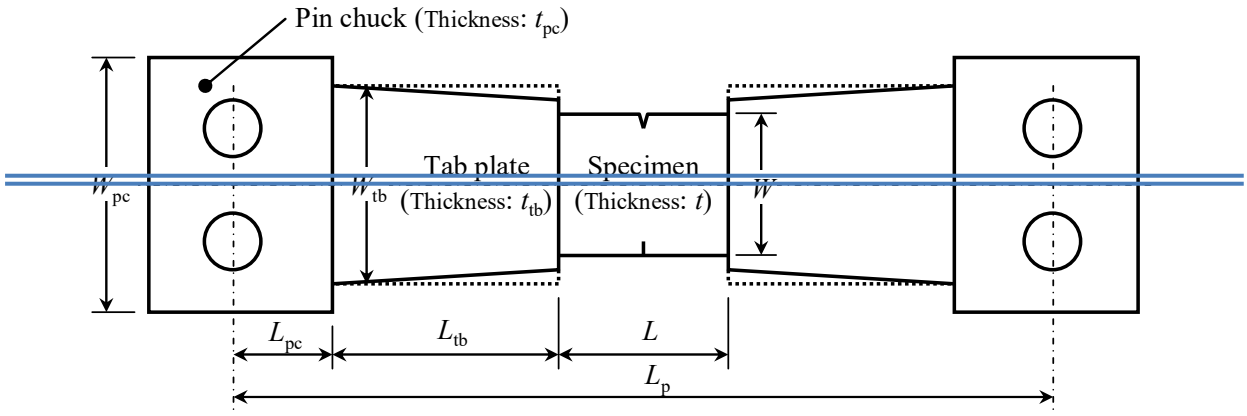
1.2.5　Shapes of Tab Plates and Pin Chucks

1　The definitions of the dimensions of tab plates and pin chucks are shown in Fig. 2.

Fig. 2　Definitions of Dimensions of Tab Plates and Pin Chucks



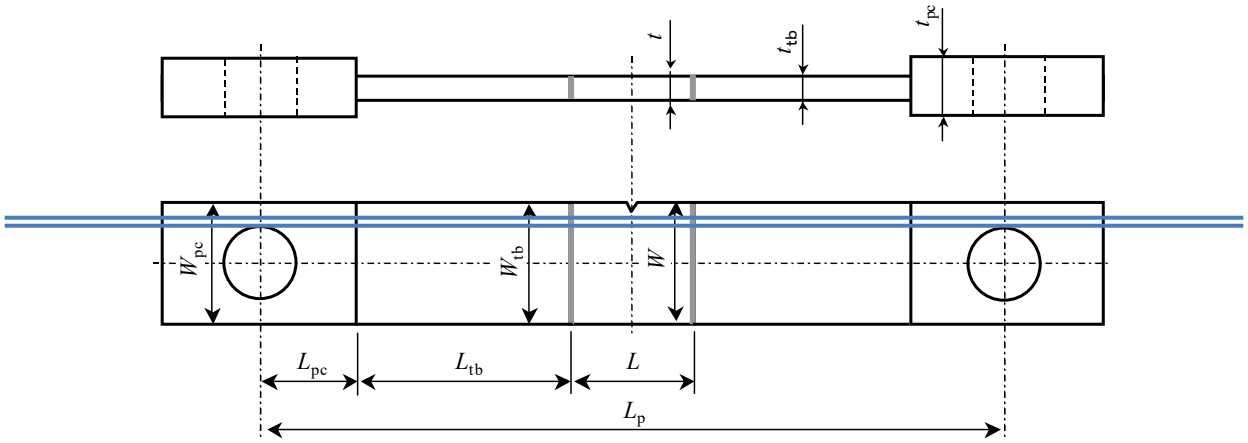
(a) Single-pin type



~~(b) Double-pin type~~

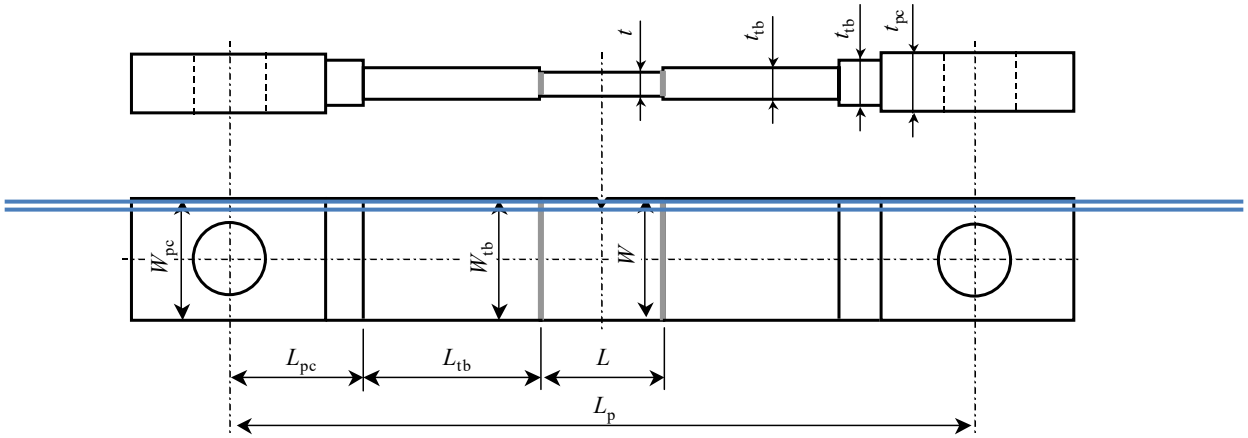
~~**2** The standard dimensions of tab plates and pin chucks are shown in **Fig. 3.**~~

~~Fig. 3 Standard dimensions of tab plates and pin chucks~~

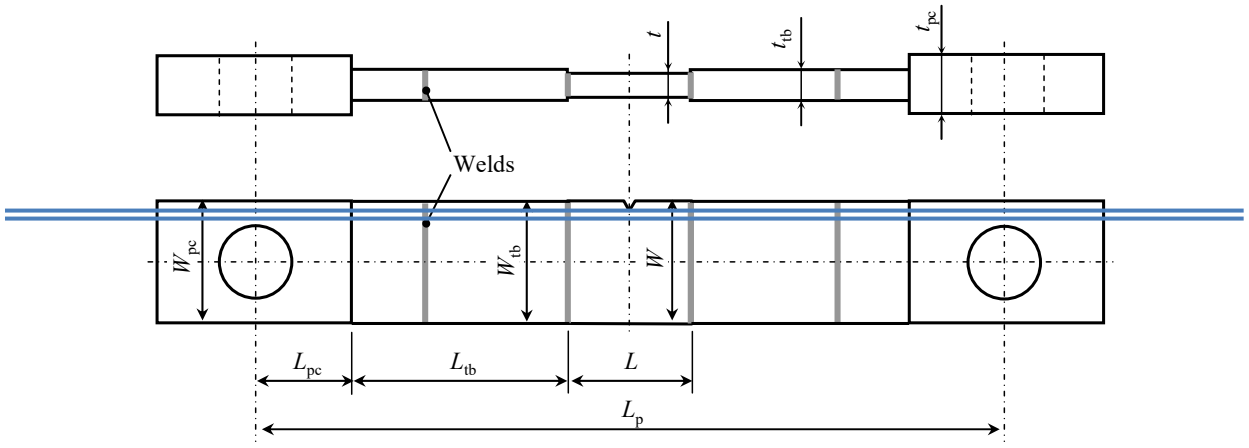


~~(a) Example 1~~

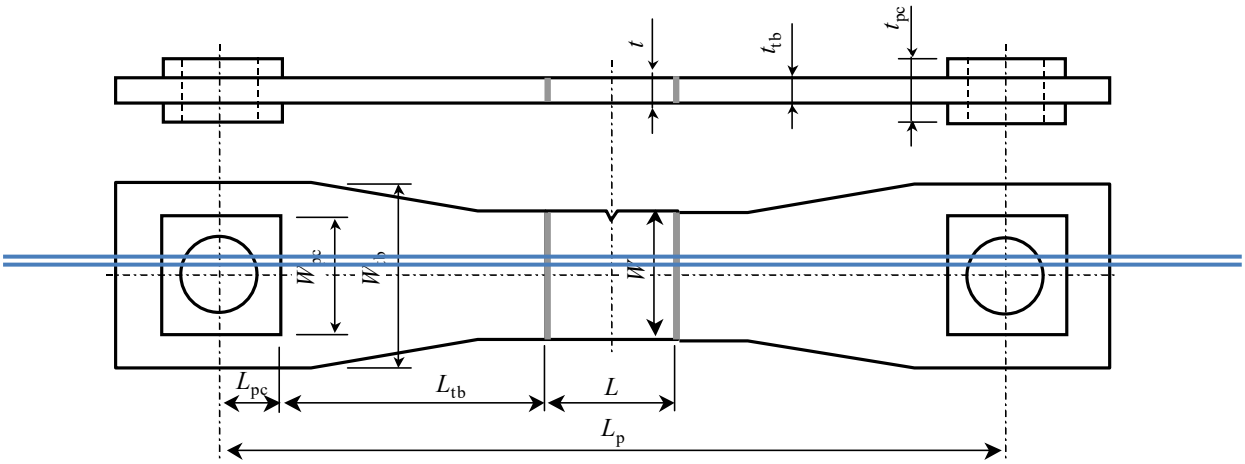
~~Fig. 3 Standard Dimensions of Tab Plates and Pin Chucks (continued)~~



~~(b) Example 2~~

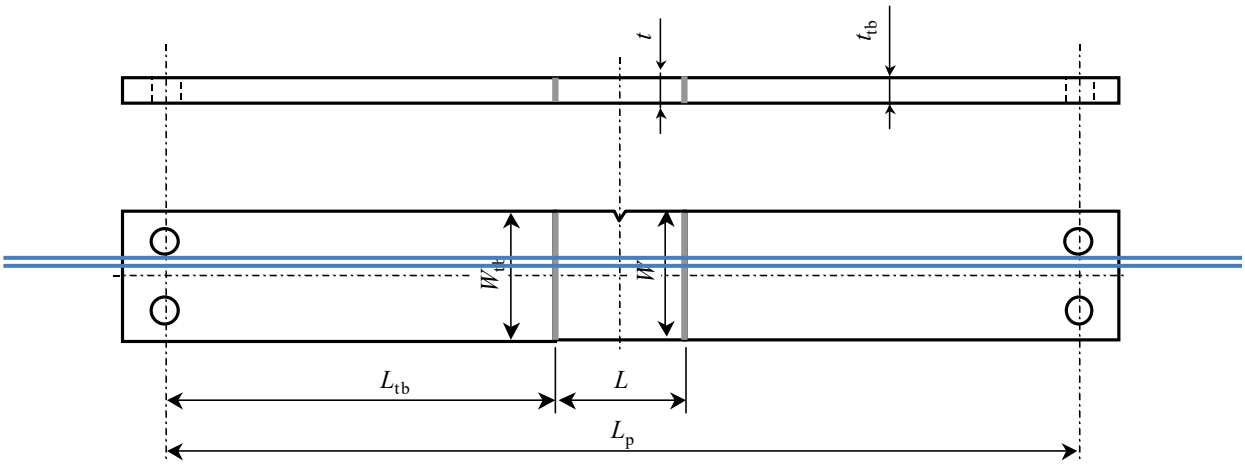


~~(c) Example 3~~



~~(d) Example 4~~

~~Fig. 3 Standard Dimensions of Tab Plates and Pin Chucks (continued)~~



~~(e) Example 5~~

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

Table 3 — Tolerances of Tab Plate Dimensions

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 test specimen and tab plates, $L + 2L_{tb}$ (Total length of 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 In principle, pin chuck width, W_{pc}, is to be equal to or greater than tab plate width, W_{tb}. Pin chucks are to be designed to have sufficient load bearing strength. When pin chucks attached to both ends of an integrated specimen are asymmetric, the length of the shorter one is to be used as the pin chuck length, L_{pc}.

5 The distance between pins, L_p, is to be obtained from the following formula. In the case shown in **Fig. 3 (c), Example 5**, it is obtained by setting $L_{pc} = 0$.

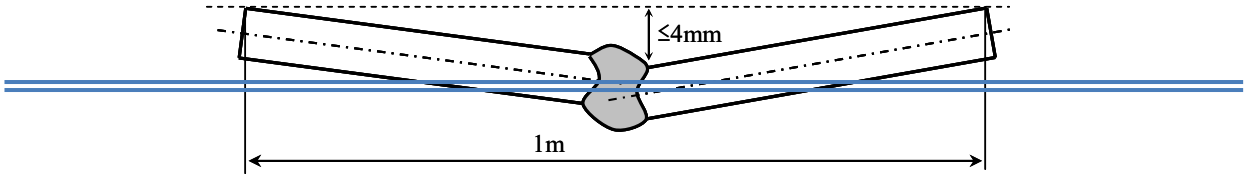
$$L_p = L + 2L_{tb} + 2L_{pc}$$

1.2.6 Welding of Test Specimens and Tab Plates

1 Test specimens, tab plates, and pin chucks are to be connected by welding. The welds are to have sufficient load bearing strength.

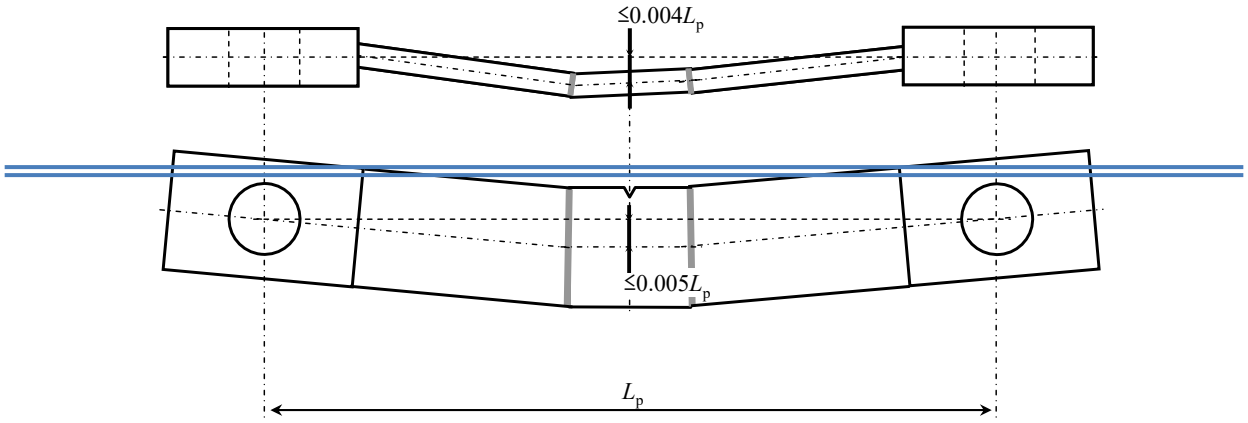
2 As shown in **Fig. 4**, the flatness (angular distortion and linear misalignment) of the welds between test specimens and tab plates are to be 4 *mm* or less *per meter*. In the case of preloading, however, it is acceptable if the value after preloading satisfies this condition.

Fig. 4 — Flatness of Welds between Test Specimens and Tab Plates



3 The accuracy of in-plane and out-of-plane loading axes are shown in **Fig. 5**. The accuracy of the in-plane loading axis is to be 0.5% or less of the distance between the pins, and the accuracy of the out-of-plane loading is to be 0.4% or less of the distance between the pins. Stress in a loaded test specimen is to be uniform.

Fig. 5 — Accuracy of In-plane and Out-of-plane Loading Axes



1.2.7 Test Methods

1 A predetermined temperature gradient is to be established across a test specimen width by soldering at least nine thermocouples to the test specimen for temperature measurement and control. The temperature gradient is to be established in accordance with the following **(1)** to **(3)** conditions.

(1) A temperature gradient of 0.25 °C/*mm* to 0.35 °C/*mm* is to be established in a test specimen width range of 0.3 *W* to 0.7 *W*. When measuring temperatures at the center positions of the test specimen thickness, it is to be kept within ±2 °C for 10 minutes or more, whereas when measuring temperatures on the front and back surface positions of the test specimen, it is to be kept within ±2°C for (10 + 0.1*t* [*mm*]) minutes or more taking account of the time needed for soaking to the center.

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

2 It is desirable that impact energy, E_t, to thickness, t, ratios satisfy following formula:

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

where "min" means the minimum of the two values.

1.2.8 Test Procedures

1 Pretest procedures are to be in accordance with following **(1)** to **(8)**:

(1) Place integrated specimen in the test machine.

(2) Mount a cooling device on the test specimen. A heating device may also be mounted on the test specimen as needed.

(3) Attach an impact apparatus. An appropriate reaction force receiver maybe arranged as needed.

(4) After checking that all measured values of the thermocouples indicate room temperature, start cooling. The temperature distribution and the holding time are to be as specified in **1.2.7-1.**

(5) Set the impact apparatus so that it can supply the predetermined energy to the test specimen.

(6) Apply a load to the test specimen until it reaches the predetermined test load. Load is, in principle, to be applied after temperature control, but temperature control may, however, be implemented after loading. Loading rate and applied stress are to satisfy the following **(a)** and **(b)**, respectively.

(a) The loading rate is to meet the conditions that the test specimen temperature distribution can be held and loading can be controlled not to become excessively large compared to the predetermined load.

(b) Applied stress is to satisfy the following formula:

$$\sigma \leq \frac{2}{3}\sigma_{Y0}$$

However, applied stress is standardized to a value equal to 1/6 σ_{Y0} or greater.

(7) Immediately prior to impact, the notch may be further cooled on the condition that such cooling does not cause the temperature to be outside the range 0.3 *W* to 0.7 *W*. The test temperature in this case is to be the measured temperature obtained from the temperature record immediately before any further notch cooling.

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

2 Loading procedures are to be in accordance with following **(1)** to **(4)**:

(1) After holding a predetermined load for 30 seconds or more, apply an impact to the wedge using

the impact apparatus. If a crack initiates autonomously and the exact load value at the time of the crack initiation cannot be obtained, the test is invalid.

(2) After impact, record the load value measured by the load recorder.

(3) When the load after impact is smaller than the test load, it is to be considered that a crack initiation has occurred. 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 impacts has no effect on the value of brittle crack arrest toughness, no limit is specified for the number of impacts. However, because the temperature gradient is often distorted by impact, the test is to be conducted again after temperature control in cases where applying another impact to the wedge.

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

3 Procedures after testing are to be in accordance with following **(1)** to **(3)**:

(1) Remove the cooling device, impact apparatus, thermocouples, and strain gauges.

(2) Return the temperature of the test specimen to room temperature. In order to achieve this, the test specimen may be heated using a gas burner or the like. If it is necessary to prevent fracture surfaces from having a burnt color at approval tests for the manufacturing processes, the direct heating of crack zones is to be avoided.

(3) After gas-cutting an uncracked ligament, use the test machine to cause a ductile fracture, as necessary. Another way is after using the test machine to develop a ductile crack to a sufficient length, gas-cut the uncracked ligament.

4 Observation of fracture surfaces and measurement of crack arrest length, a, are to be in accordance with following **(1)** to **(3)**:

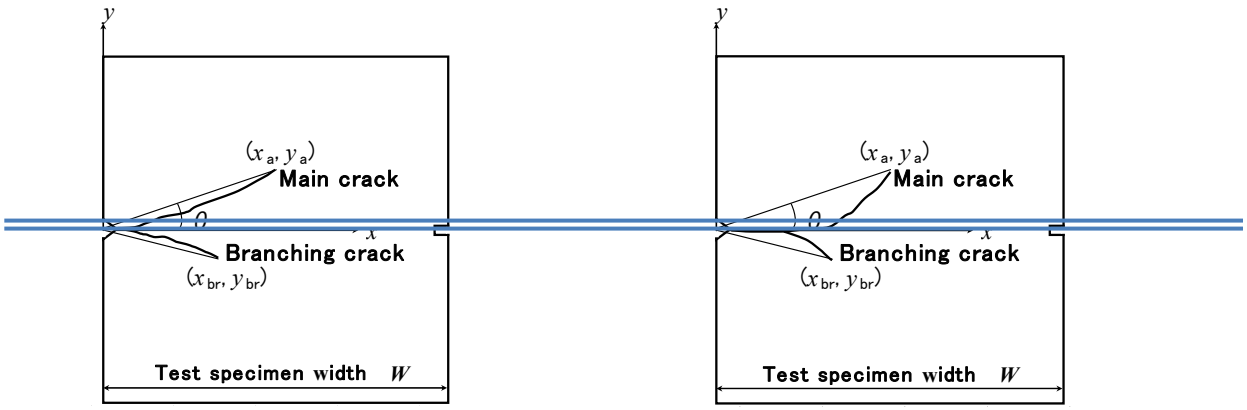
(1) Take photographs of fracture surfaces and propagation path.

(2) Measure the longest length of an arrest crack tip in the plate thickness direction, and record it as the arrest crack length, a. In cases 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 a. In the following cases, however, evaluate the results in accordance with following **(a)** and **(b)**, respectively:

(a) In cases 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 cases where a crack continuously propagates partially in the thickness direction, the position of the longest brittle crack is defined as the arrest position.

(b) In cases 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 cases 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 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. To be more specific, from the coordinates (x_a, y_a) of the arrest crack tip position and the coordinates (x_{ba}, y_{ba}) of the branch crack tip position shown in **Fig. 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 $y = 0$.

Fig. 6　Measurement Methods of Main Crack and Branch Crack Lengths



(a) Case of branching from the notch　　(b) Case of branching during brittle crack propagation

(3) Prepare a temperature distribution curve (line diagram showing the relationship between 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.

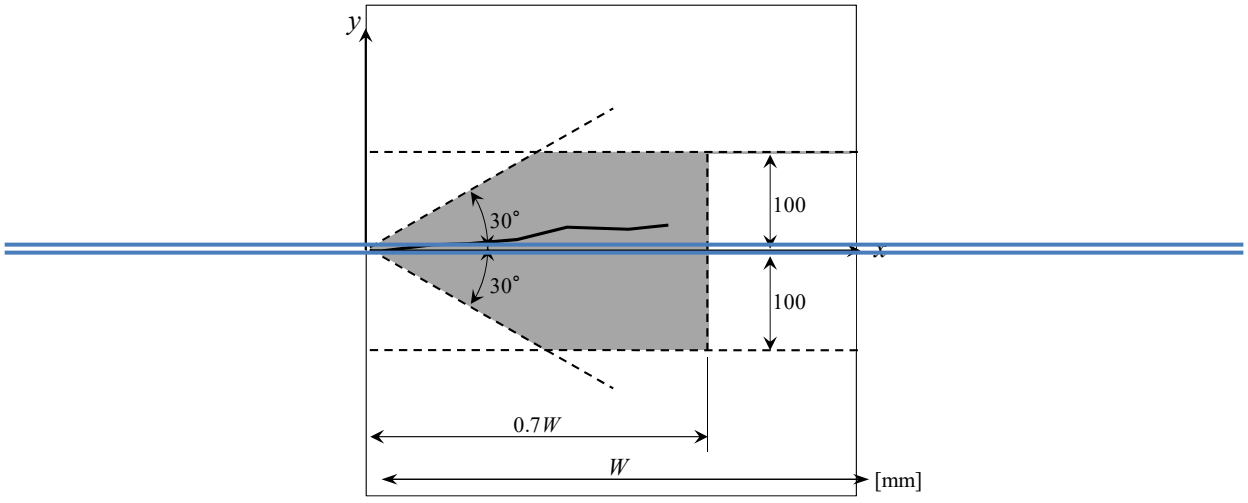
1.2.9　Determination of Arrest Toughness Value

1　When an arrested crack satisfies all of the conditions (1) to (4) described below, the length of the arrested crack, a, determined by requirement 1.2.8 is valid. If any of the conditions are not met, the arrest toughness value, K_{ca}, calculated from requirement in 4 is a reference value.

(1) All the crack path from crack initiation to arrest is to be within the range shown in Fig. 7. In cases where the main crack tip lies within this range but a part of the main crack passes outside the range, however, arrest toughness value, K_{ca}, may be assessed 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 the stress intensity factor, K, for the main crack falls within ± 5% of the K value for a straight crack of the same a. The stress intensity factor, K, is to be obtained from the following formula:

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

Fig. 7　Allowable Range of Main Crack Propagation Path



(2) The arrest crack length, a, is to satisfy the following (a) to (c) formulae. However, if the strain at the pin position and the crack length at the pin position 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, the application of formula (c) is not necessarily needed.

(a) $0.3 \leqq \left(\frac{a}{W}\right) \leqq 0.7$

(b) $\left(\frac{a}{t}\right) \geqq 1.5$

(c) $\left(\frac{a}{L_{pf}}\right) \leqq 0.15$

(3) Satisfying the following formula is the condition for crack straightness:

$|y_a| \leqq 50\ mm$

In cases where $50\ mm < |y_a| \leq 100\ mm$ and $|\theta| \leq 30°$, it is valid only when the temperature at $x = 0.5\ W$, $y = \pm 100\ mm$ falls within $\pm 2.5°C$ at $x = 0.5\ W$, and $y = 0$.

(4) Satisfying the following formula is the condition for crack branching:

$$\left(\frac{x_{pf}}{x_a}\right) \leq 0.6$$

2 Impact energy, E_s, is to satisfy the following formulae. If these formulae are not satisfied, the arrest toughness value, K_{ca}, calculated from the formulae in requirement **4** is to be treated as a reference value.

$$\frac{E_s}{E_s + E_t} \leqq \frac{5a - 1050 + 1.4W}{0.7W - 150}, \text{ where } 0.3 \leqq \left(\frac{a}{W}\right) \leqq 0.7$$

$$E_s = \frac{10^9 F^2}{2E} \frac{L}{W \cdot t}$$

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

3 In cases where tab plates are multistage as shown in **Fig. 3 (b)**, calculate and total the strain energy of each tab plate. In cases where tab plate widths are tapered as shown in **Fig. 3 (d)**, calculate the strain energy based on elastostatics.

4 The arrest toughness value, K_{ca}, at temperature, T, is to be calculated from the following formula using the arrest crack length, a, and the applied stress, σ, judged by requirement **1** above.

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

$$\sigma = \frac{10^6 F}{W \cdot t}$$

1.2.10 Reporting

The following items are to be reported. An example of the format to be used for reports is shown in **REPORT-ESSO(E)**.

(1) Test material: Steel type and yield stress at room temperature

(2) Testing machine: Capacity of the test 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 tab plates, and distance between loading pins

(5) Test conditions: Applied load, 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 on 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 the 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 (if measurements are carried out): History of crack propagation velocity, and strain change at pin chucks~~

~~1.2.11~~1.3 Method for Obtaining Arrest Toughness Value at a Specific Temperature

~~1 The arrest toughness value, K_{ca}, at a specific temperature, T_D, may be obtained in accordance with following (1) to (4) by using test results which are obtained by conducting two or more of the tests specified in this section. The formula below shows the dependency of K_{ca} on the arrest temperature T_K.~~

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

~~(1) Obtain at least four valid K_{ca} data. T_D must be located between the upper and lower limits of the arrest temperature. If T_D is not located in this range, conduct additional tests to satisfy this condition.~~

~~(2) Approximate $\log K_{ca}$ by a linear expression of $1/T_K$, determine the coefficients $\log K_0$ and c for the data described in (1) above using the least square method.~~

$$\log K_{ca} = \log K_0 + c\frac{1}{T_K}$$

~~(3) Obtain the value of $K_{ca} / K_0 \exp(c/T_K)$ for each data. When the number of data outside the range of 0.85 to 1.15 does not exceed n, the least square method used in the (2) above is considered to be valid. Here n is an integer obtained by rounding down the value of (number of all data/6). If this condition is not met, conduct additional tests to add at least two data and apply the (2) above to said data.~~

$$\frac{K_{ca}}{K_0 \exp\left(\frac{c}{T_K}\right)}$$

~~(4) The value of $K_0 \exp(c/T_K)$ 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 the (3) above is not met, these estimated values are treated as reference values.~~

1 Method

The arrest toughness value K_{ca} at a specific temperature is calculated by using test results which are obtained by conducting two or more of the tests in accordance with Annex B of *ISO* 20064:2019.

2 Evaluation

The straight-line approximation obtained from the test data of the valid K_{ca} data ~~and the arrest temperature T_K according to -1 above are~~ is to comply with either the following **(1)** or **(2)**.

(1) The evaluation temperature of K_{ca} (i.e. −10 °C) is to be located between the upper and lower limits of the arrest temperature, with the K_{ca} corresponding to ~~the~~ an 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 **Fig. ~~8~~1**.

(2) The temperature corresponding to the required K_{ca} (e.g. 6,000 $N/mm^{3/2}$ or 8,000 $N/mm^{3/2}$) is to

be 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 **Fig. ~~9~~2**.

3 If both of **(1)** and **(2)** of **-2** above are not satisfied, additional tests may be conducted to satisfy this condition.

Fig. ~~8~~1 Evaluation Example of K_{ca} at −10 °C

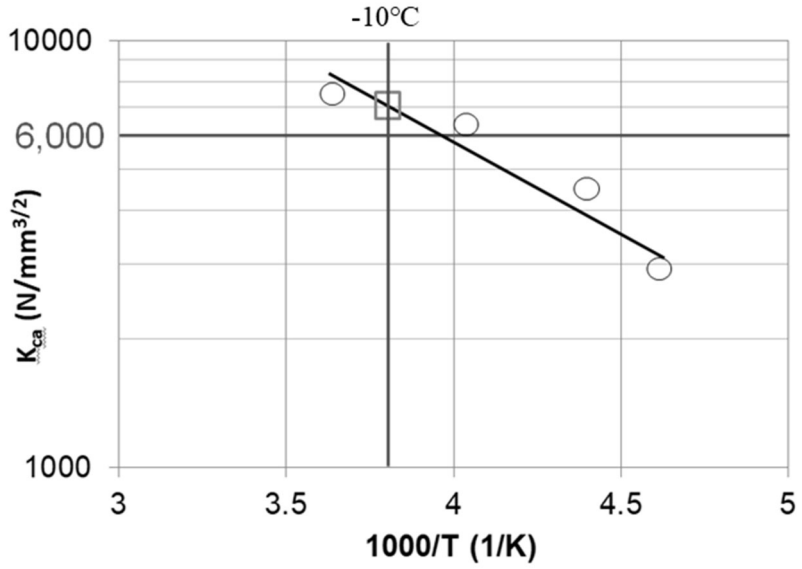
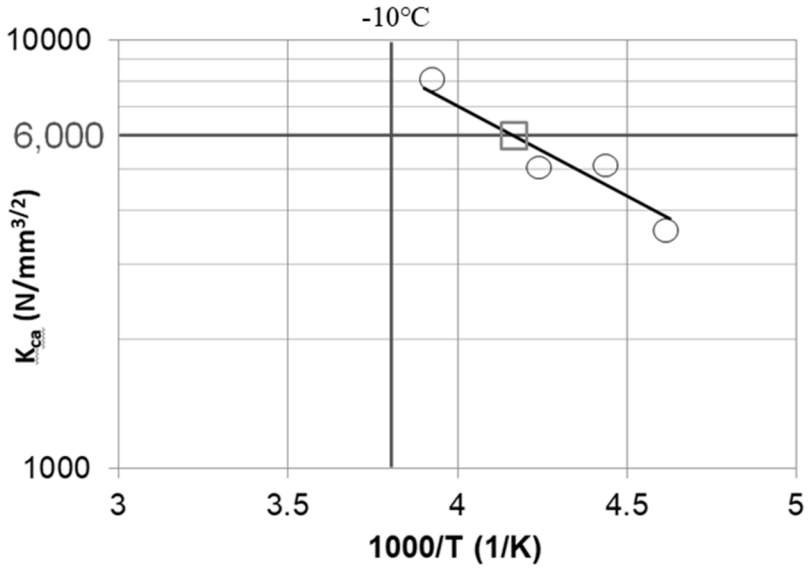


Fig. ~~9~~2 Evaluation Example of Temperature Corresponding to Required K_{ca}



~~**1.3 Temperature Gradient Double Tension Tests**~~

~~**1.3.1 General**~~

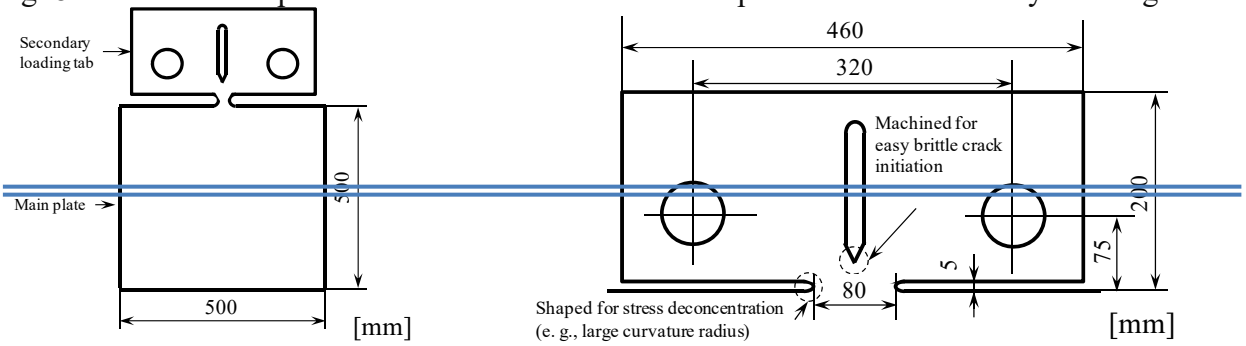
~~**1** The requirements in this section are related to the evaluation of brittle crack arrest toughness through the use of temperature gradient double tension tests.~~

~~**2** Items not specified in this section are to be accordance mutatis mutandis with the requirements in 1.2~~

1.3.2 Test Specimen Shapes

The standard shapes of an entire double tension test specimen and a secondary loading tab are shown in Fig. 8.

Fig. 8 Standard Shapes of Entire Double Tension Test Specimen and Secondary Loading Tab



(a) The shape of an entire test specimen

(b) The shape of a secondary loading tab

1.3.3 Temperature Conditions and Temperature Control Methods

1 Temperature control methods for secondary loading tabs are to in accordance with the requirements in 1.2.7-1.

2 Secondary loading tabs are to be cooled without affecting the temperature gradient of the main plate. The cooling method may use a cooling box and coolant in a similar way as the cooling method for test specimens.

3 The temperature of the secondary loading tab is to be measured using thermocouples.

1.3.4 Secondary Loading Method

Secondary loading devices used to apply loads to secondary loading tabs are to comply with the following (1) to (3):

(1) In order to avoid unnecessary loads affecting the integrated specimen, secondary loading devices need to be held in position using an appropriate method. Suspension type or floor type holding methods can be used.

(a) Suspension type holding methods

This method uses a crane or similar device to suspend and hold the secondary loading device in the proper position.

(b) Floor type holding methods

This method uses a frame or similar device to lift and hold the secondary loading device it the proper position.

(2) Loading systems for applying loads to secondary loading tabs are to be of a hydraulic type.

(3) Loading methods for secondary loading tabs are to be of a pin type. However, other loading methods pin type may be used in cases where deemed appropriate by the Society.

Annex K3.12.3-2 GUIDANCE FOR *CAT* EVALUATION TESTS

1.1 General

Paragraphs 1.1.2 has been amended as follows.

1.1.2 Definition

The definition of the symbols used in this Guidance is as specified in **Table 1** as well as ~~**1.1.2, Annex K3.12.3-1** "GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS"~~ Table 1 of *ISO* 20064:2019.

1.2 *CAT* ~~e~~Evaluation tests

1.2.2 Test Equipment and Impact Equipment

Sub-paragraph -4 has been amended as follows.

1 The test equipment to be used is to be of a hydraulic type of sufficient capacity to provide a tensile load equivalent to 2/3 of *SMYS* of the steel grade to be approved.
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 Methods for initiating the brittle crack may be of a drop weight type, air gun type or double tension tab plate type.
4 Detailed requirements for testing equipment are ~~specified in **Annex K3.12.3-1** "GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS"~~ to be in accordance with Table 1 of *ISO* 20064:2019.

1.2.3 Test Specimens

Sub-paragraph -1 has been amended as follows.

1 Test specimens are to be in accordance with ~~**Annex K3.12.3-1** "GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS"~~ *ISO* 20064:2019, unless otherwise specified in this Guidance.

1.2.4 Double ~~t~~Tension ~~t~~Type ~~c~~Crack ~~i~~Initiation

Sub-paragraph -1 has been amended as follows.

1 Reference is to be made to ~~**Annex K3.12.3-1** "GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS"~~ Annex D of *ISO* 20064:2019 for the shape and size of the secondary loading tab and secondary loading method for brittle crack initiation.
2 The secondary loading tab plate may be subject to further cooling to enhance an easy brittle crack initiation.

1.2.6 Side Grooves

Sub-paragraph -4 has been amended as follows.

1 Side grooves on side surface may be machined along the embrittled zone to keep brittle crack propagation straight. Side grooves are to be machined in the cases specified in this Guidance.

2 In *EBW* embrittlement, side grooves are not necessarily mandatory since use of *EBW* avoids shear lips. However, when shear lips are evident on the fractured specimen (e.g. shear lips over 1 *mm* in thickness on either side), the side grooves are to be machined to suppress the shear lips.
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 The length of side groove (L_{SG}) is to be no shorter than the sum of the required embrittled zone length ~~of 150 *mm*~~.
5 When side grooves are introduced, side groove depth, the tip radius and the open angle are not regulated~~,~~ but are to be adequately selected in order to avoid any shear lips over 1 *mm* thickness on either side. An example of side groove shape is shown in **Fig.2**.
6 Side groove ends are to be machined to make groove depth gradually shallow with curvatures larger than or equal to groove depth (d_{SG}~~,~~). Side groove length (L_{SG}) is defined as a groove length with constant depth except for a curved section in depth at the side groove end.

Paragraph 1.2.7 has been amended as follows.

1.2.7 Nominal Length of Embrittled Zone
1 The length of embrittled zone is to be at least 150 *mm*.
~~**1**~~**2** *EBW* zone length is regulated by three measurements on the fracture surface after tests, as shown in **Fig. 3**, $L_{EB\text{-}min}$ between specimen edges and the *EBW* front line, and $L_{EB\text{-}s1}$ and $L_{EB\text{-}s2}$.
~~**2**~~**3** The minimum length between specimen edges and the *EBW* front line ($L_{EB\text{-}min}$) is to be no smaller than 150 *mm*. When $L_{EB\text{-}min}$ is smaller than 150 *mm* and no smaller than 150 *mm* − 0.2*t*, T_{test} is described in **1.2.13-1(2)**.
~~**3**~~**4** $L_{EB\text{-}s1}$ and $L_{EB\text{-}s2}$ are the lengths between specimen edges and the *EBW* front for both side surfaces. Both $L_{EB\text{-}s1}$ and $L_{EB\text{-}s2}$ are to be no smaller than 150 *mm*.
~~**4**~~**5** In *LTG* systems, L_{LTG} is set as 150 *mm*.

Paragraph 1.2.8 has been amended as follows.

1.2.8 Tab Plate and Pin Chuck Details
The following **(1)** and **(2)** are to be as specified in ~~**Annex K3.12.3-1 "GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS"**~~ *ISO* 20064:2019.
(1) The shape and size of tab plates and pin chucks.
(2) The plane accuracy and the accuracy of in-plate loading axes in the integrated specimen, which is welded with specimen, tab plates and pin chucks.

1.2.10 Loading and Brittle Crack Initiation

Sub-paragraph -2 has been amended as follows.

1 Prior to testing, a target test temperature (T_{target}) is to be selected.
2 Test procedures are to be in accordance with ~~**Annex K3.12.3-1 "GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS"**~~ *ISO* 20064:2019 except that the applied stress is to be 2/3 of *SMYS* of the steel grade tested.
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.
4 Brittle crack is to be initiated by impact or secondary tab plate tension after all ~~of the~~ temperature measurements and the applied force are recorded.

1.2.12 Judgment of “Arrest” or “Propagate”

Sub-paragraph -1 has been amended as follows.

1 If the initiated brittle crack is arrested and the tested specimen is not broken into two pieces, the fractured surfaces are to be exposed with the procedures specified in ~~**Annex K3.12.3-1 “GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS”**~~ *ISO* 20064:2019.

2 When the specimen is 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}.

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

4 Even when the specimen was broken into two pieces during testing, it may be considered as “arrest” when brittle crack re-initiation is clearly evident. Even ~~in~~ when the fractured surface consists almost entirely of the ~~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 may be judged as re-initiation behaviour. If so, the maximum crack length of the part surrounded tear line may be measured as a_{arrest}. If not, the test is judged as “propagate”.

5 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”.

"Guidance for the approval and type approval of materials and equipment for marine use" has been partly amended as follows:

Part 1 METALLIC MATERIALS

Chapter 1 APPROVAL OF MANUFACTURING PROCESS OF ROLLED STEELS

1.4 Approval Test

1.4.1 Extent of the Approval Tests

Sub-paragraph -1(1) has been amended as follows.

1 Approval for the manufacturing processes of rolled steels is to be the following **(1)** to **(3)** if deemed appropriate by the Society.

(1) Rolled steels for hull, rolled steels for low temperature service and high strength rolled steels for offshore structures

Approval for any grade of steels ~~(excluding *KE*47)~~ may also cover~~s~~ approval for any lower grade of steels (of which specific temperature of impact test is higher than that of test sample) in the same strength level provided that kind, deoxidation practice, grain refining and micro-alloying elements, heat treatment, steel making process, steel casting process and maximum manufacturing thickness or dimensions are same. For higher tensile steels for hull, in addition to above, approval of one strength level may also covers the approval of the same grade and below in the strength level immediately below.

Approval for *KE*47 may also cover approval for any same strength level and same grade of steel among the lower brittle crack arrest properties provided that the kind, deoxidation practice, grain refining and micro-alloying elements, heat treatment, steel making process, steel casting process and maximum manufacturing thickness or dimensions are same.

In addition, in cases where this ~~provision~~ requirement is being applied to high strength rolled steels for offshore structures ~~this provision~~, technical documents deemed necessary by the Society may also be required.

(2) Rolled steels other than those of the preceding **(1)**

Approval for any strength level of steels may also covers approval for any lower strength of steels (of which specific yield strength level is lower than that of test sample) provided that kind, deoxidation practice, heat treatment, steel making process, steel casting process and maximum manufacturing thickness or dimensions are same and the range of manufacturing control standards of chemical composition is similar.

(3) Steels considered to have brittle crack arrest properties specified in **3.12, Part K of the Rules**

Approval for any brittle crack arrest steels may also cover approval for any same and lower grades of steels (of which specific yield strength level is lower than that of test sample) in the same strength level and same and lower grades of steels in the strength level immediately below (of which specific yield strength level is one lower than that of test sample) among the same and immediately below brittle crack arrest properties (of which specific brittle crack arrest properties are lower than that of test sample) provided that deoxidation practice, grain refining and micro-alloying elements, heat treatment, steel making process, steel casting process, maximum manufacturing thickness or dimensions, and mechanism for improving brittle crack arrest properties are the same. However, approval for *KE*47 may also cover the approval for any same strength level and same grade of steel among the lower brittle crack arrest properties.

Paragraph 1.4.2 has been amended as follows.

1.4.2 Selection of Test Samples

1 Test samples used for approval tests of rolled steels are to be selected according to the following **(1)** through **(5)**:

(1) Test samples are generally to be selected for each grade and kind by each charge of rolled steels of which deoxidation practice, grain refining and micro-alloying elements, heat treatment, steel making process and steel casting process are same, based upon typical chemical composition (including the desired carbon equivalent or cold cracking susceptibility values if applicable).

(2) In case of ingot casting, test samples are to be selected from the steels corresponding to the top of the ingot, except where specially approved by the Society.

(3) Notwithstanding ~~the requirements in~~ the preceding **(2)**, in the case of high strength rolled steels for offshore structures, test samples are to be selected from steels corresponding to the tops and bottoms of ingots.

(4) In the case of continuous casting, test samples are to be selected from ~~the~~ steels ~~which are~~ directly rolled from a semi-finished product.

(5) Test samples of ingots or semi-finished products are also to be selected according to each casting process.

2 The plate thicknesses or dimensions of test samples are to be the maximum manufacturing thicknesses or maximum dimensions. Moreover, in case of the steel plates are manufactured from the continuous casting slabs, the maximum manufactured thickness is to be determined, with the reduction ratio is 6 as standard. However, upon consideration of the manufacturing process, the reduction ratio may be reduced to 4 (in the case of steel plates of over 50 *mm* thickness, may be reduced to 3).

3 Notwithstanding the preceding **-2**, if the target chemical composition changes with the thickness for *KE*47 and steels considered to have brittle crack arrest properties, the maximum thickness for each specified chemical composition specification is to be tested.

~~**3**~~**4** Where the maximum manufacturing thicknesses of rolled steels for hulls, rolled steels for low temperature service and high strength rolled steels for offshore structures is more than 50 *mm* and in ~~the~~ cases where the ~~of~~ first approval of at least one item of deoxidation practice, grain refining and micro-alloying elements, heat treatment, steel making process and steel casting process, the Society may request an additional test sample~~s~~ of which thickness is indicated with a ● mark in **Table 1.1-1** or some other proper thickness, in addition to the test samples in accordance with **-2**.

~~**4**~~**5** Notwithstanding ~~the requirements in~~ the preceding **-2,** the rolled reduction ratio is to be at least 5 for rolled bars for offshore mooring chains (hereinafter referred to as "offshore chains"), and at least 3 for high strength rolled steels for offshore structures.

1.4.3 Details of Test

Sub-paragraph -6 has been amended as follows.

6 For the steels considered to have the brittle crack arrest properties specified in **3.12, Part K of the Rules for the Survey and Construction of Steel Ships**, if the manufacturing process is similar to manufacturing control standards of chemical composition and rolling conditions for which the applicant has already been approved and is same as the deoxidation practice, grain refining and micro-alloying elements, heat treatment, steel making process, steel casting process, temperature gradient *ESSO* tests or double tension tests, chemical analysi~~s~~es, tensile tests and ~~e~~Charpy impact tests may be performed as ~~an~~ approval tests according to this ~~C~~chapter. *CAT* evaluation tests may be applied instead of temperature gradient *ESSO* tests or double tension tests. In addition, where small-scale tests are used for product testing, these test methods are to be approved by the Society in accordance

with **Annex 1.1**.

Table 1.1-3 has been amended as follows.

Table 1.1-3 Approval Testing Method and Acceptance Criteria (continued)

Approval test item		Selected location of test samples (1) (2)	Length direction of test specimen (3) (4)	Testing method	Acceptance criteria	Notes
Brittle fracture test	*CTOD* test or deep notch test	Top	Parallel	To be consulted with the Society the dimension of test specimen, test condition etc. When newly performing tests at the time of approval.	To be as deemed appropriate by the Society.	-
	Temperature gradient *ESSO* test, double tension test or *CAT* evaluation test	Top	Parallel	In accordance with **Annex K3.12.3-1 or Annex K3.12.3-2, Part K of the Rules for the Survey and Construction of Steel Ships.**		・ Where the brittle crack arrest properties are evaluated by K_{ca} and the brittle crack arrest test results fail to meet the requirement, further brittle crack arrest tests may be carried out. In such cases, the judgment of acceptance is to be made on the arrest toughness value K_{ca} for all test specimens. ・ Results of initial tests, failed tests and additional tests are to be included in test reports.
	NRL drop weight test	Top	Parallel	*ASTM E* 208:2019 or equivalent method.		・ Nil-ductility transition temperatures (*NDTT*) and photographs of test specimens after testing are to be included in test reports.

Table 1.1-3 Approval Testing Method and Acceptance Criteria (continued)

Approval test item		Selected location of test samples (1) (2)	Length direction of test specimen (3) (4)	Testing method		Acceptance criteria	Notes
Weldability (5) (6) (7)	Welding hardness test	Top	—	Rolled steels for hull Rolled steels for low temperature service High strength rolled steel for offshore structures (Each plate is to include steel flats not less than 600 *mm* in width)	At sections of butt welding joints, welding hardness tests ~~is~~ are measured 0.7 *mm* pitch from weld junction to base metal along with the two parallel lines which are 1 *mm* inside from the both surface of base metal.	Values of maximum hardness are not to exceed the values specified in **Table 1.1-8**. ~~For~~ ~~o~~Other steel plates are to be as deemed appropriate by the Society.	• Test specimens are, in principle, to be selected from each test sample specified in **Table 1.1-6**. • Sketches of weld joints depicting groove dimensions, number of passes, and hardness indentations are to be attached to test reports together with photomacrographs of weld cross sections. • Hardness tests are carried out at HV5 for rolled steels for hulls, and at HV10 for high strength rolled steels for offshore structures.
				Rolled steels other than ~~the~~ those mentioned above	*JIS Z 3101* or equivalent method.	To be as deemed appropriate by the Society.	-
	Y-shape weld crack test (Hydrogen crack test)	Top	—	To be in accordance with internationally recognized standards such as ~~*JIS Z* 3158~~ *ISO* 17642-2:2005, etc.		To be as deemed appropriate by the Society.	• In the case of steels other than steel plates (including flat bars not less than 600 *mm* in width), the test may be omitted. • For high strength rolled steels for offshore structures, the relationship between minimum preheat temperature and thickness is to be described.
	CTOD test or deep notch test	Top	Transverse for welding direction	*CTOD* tests are to be carried out in accordance with *ISO* 15653 or the equivalent. Three test specimens notched in the through thickness direction in grain coarsened *HAZ* (*CGHAZ*) are to be selected for each butt weld test assembly and tested at -10°C. When performing deep notch tests at the time of approval, the Society is to be consulted about the dimensions of test specimens, test conditions, etc.		To be as deemed appropriate by the Society.	• In the case steels of other than steel plates (including flat bars not less than 600 *mm* in width), the test may be omitted. • ~~The~~ *CTOD* specimens for the high strength rolled steels for offshore structures ~~is~~ are to be taken from test samples **(b)** and **(c)** specified in **Table 1.1-6**. ~~Dimension of specimen~~ Specimen dimension are to comply with **Table 1.1-9**.

Table 1.1-3 Approval Testing Method and Acceptance Criteria (continued)

Approval test item		Selected location of test samples (1) (2)	Length direction of test specimen (3) (4)	Testing method		Acceptance criteria	Notes
Corrosion resistance test	Corrosion test	Top	—	To be in accordance with internationally recognized standards such as *JIS G* 0575, *G* 0576 and *G* 0591, etc.		To be as deemed appropriate by the Society.	-
Non-destructive test	Ultrasonic test or Eddy current test	~~All~~ Entire surface	—	Stainless clad steels	*JIS G* 0601 or equivalent method.	To meet t~~he requirements of~~ class *F* of *JIS G* 0601	-
				Steel with consideration for thickness directional characteristics	In accordance with t~~he requirements in~~ **Chapter 3, Part K of the Rules for the Survey and Construction of Steel Ships**.	In accordance with the requirements in **Chapter 3, Part K of the Rules for the Survey and Construction of Steel Ships**.	-
				Round bars for chains	*JIS G* 0801 and *JIS G* 0202 or equivalent method.	To be free from any defects deemed to have negative effect.	-
Corrosion resistance test for cargo oil tanks		Top	—	In accordance with ~~the requirements in~~ **Annex 1.~~1~~2**.		In accordance with ~~the requirements in~~ **Annex 1.~~1~~2**.	・ The chemical composition of test specimens for corrosion resistance tests of cargo oil tanks is to be set in accordance with the documents specified in **1.2.2** to make it possible to confirm the validity of the chemical composition range (upper and lower limits) of elements to be added for improving corrosion resistance. ・ With respect to corrosion resistance tests for cargo oil tanks, IACS Unified Interpretation SC258 as amended is to be applied in addition to **Annex 1.~~1~~2**.

1.5 Approval

1.5.4 Changes in the Approved Content

Sub-paragraph -3 has been amended as follows.

3 Upon studying the items of changes in approved content specified in **-1** or **-2**, the Society requests ~~the~~ factory inspection and approval test<u>s</u> in accordance with ~~the requirements in~~ **1.4** as necessary. In cases where the applicable welding consumables specified in **-2(2)** are changed, the corrosion resistance test for corrosion resistant steel specified in **Annex 1.~~1~~2** may be limited to only test<u>s</u> for welded joints.

Annex 1.1 has been added as follows.

Annex 1.1 Approval Scheme for Small-scale Test Methods for Brittle Crack Arrest Steels

1.1 Scope

1.1.1 Scope

1 This annex specifies the approval scheme of small-scale test methods which apply to alternative tests such as temperature gradient *ESSO* tests and double tension tests, or *CAT* evaluation tests (hereinafter referred to as "brittle crack arrest tests") for evaluating the brittle crack arrest properties specified in **Table K3.40, Part K of the Rules for the Survey and Construction of Steel Ships** for the steels which are considered so as to have brittle crack arrest properties (hereinafter referred to as "arrest steels").

2 Unless otherwise specified in this annex, **Chapter 1, Part 1** is to be followed.

1.2 Approval Applications

1.2.1 Approval Applications

1 Manufacturers are to submit the following documents to the Society:

(1) Applications for approval of small-scale test procedure specifications

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

- (a) Applicable material grades, thickness ranges, deoxidation practices, heat treatments, etc.
- (b) Small-scale test types and methods
- (c) Test specimen sampling positions in the plate thickness direction and final rolling direction
- (d) Test specimen size and dimensions
- (e) Test specimen number
- (f) Test conditions, such as test temperatures
- (g) Acceptance criteria
- (h) Test report format example
- (i) Product inspection certificate example (including small-scale test results).
- (j) Handling of the products when small-scale test results do not satisfy their criteria

(3) Mechanism for achieving brittle crack arrest properties of arrest steels.

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

(5) Evaluation procedures for the brittle crack arrest properties of arrest steels by small-scale test results.

(6) Data records which validate the correlation between small-scale test results and the brittle crack arrest test results of arrest steels whose number can satisfy the requirement for minimum data number given in **1.3.3**

(7) Proposed test plan for approval

2 Small-scale test procedure specifications are to be prepared in accordance with **1.3**.

3 Where manufacturers propose to change any part of an already approved small-scale test procedure specification, then said manufacturer is to submit documents which can cover all items specified in **1.2.1-1** to the Society.

4 In addition to **-3** above, documents confirming the reasons for such changes are to be submitted to identify the impact of those changes on the existing procedure, and the proposed actions to address any such impact.

1.3 Establishment of Small-scale Test Procedure Specifications

1.3.1 General

1 Small-scale test methods are to be determined based on manufacturer technical philosophies with regard to achieving the brittle crack arrest properties of arrest steels. Furthermore, descriptions of appropriate correlations between brittle crack arrest properties obtained from brittle crack arrest tests and small-scale test results are required, and acceptance criteria for small-scale tests are to be determined, based on the following:

(1) Mechanism of achieving suitable brittle crack arrest properties

(2) Sampling position and direction

(3) Sampling frequency

(4) Small-scale test methodology

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

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

2 Manufacturers are to prepare small-scale test procedure specifications in accordance with the following **1.3.2** through **1.3.5.**

1.3.2 Test Types and Methods

1 Small-scale test types, methods, test specimen dimensions, test specimen sampling positions, and test specimen directions, etc. are to be specified by manufacturers and approved in accordance with this annex.

2 In general, test methods are to reproduce crack initiation, propagation and arrest features as in the following examples.

(1) Combination of test methods (e.g. *NRL* drop weight test and V-notch Charpy impact test)

(2) A single test method (e.g. press-notch Charpy impact test or *NRL* drop weight test (side-section drop weight test) (see **Table 1.1-3**)

3 In general, brittle crack arrest properties of arrest steels are to be predicted using a regression equation on the relationship between small-scale test results (e.g. transition temperatures obtained by small-scale tests) and brittle crack arrest test results (e.g. K_{ca} or temperature corresponding to the specific brittle crack arrest properties). Other approaches may be used subject to Society approval.
Note: **Table 1.1-1** through **Table 1.1-3** give the examples of small-scale test methods.

4 For determination of test methods, manufacturers are to confirm the applicability of the test methods to their brittle crack arrest steels by theoretically taking into account the methodology of the test methods, their own mechanisms of achieving brittle crack arrest properties, and test specimen sampling positions (See **1.3.1-1**). Manufacturers are then to also submit technical backgrounds for determination of small-scale test methods to the Society as specified in **1.2.1**.

1.3.3 Testing Data

1 Test plate selection

(1) Brittle crack arrest tests and small-scale tests are to be conducted for each material grade (including all suffixes) of the brittle crack arrest properties of arrest steels in accordance with **1.3.3** of this annex.

(2) Brittle crack arrest tests and small-scale tests are to be carried out on at least 12 test plates, in accordance with **1.3.3-1(3)**. Test results are to be capable of reliably estimating the brittle crack arrest properties of arrest steels.
Note: "One test plate" means "the rolled product from a single slab or ingot if this is rolled directly into plates".

(3) In order to ensure appropriate correlation between small-scale test results and brittle crack arrest properties with various manufacturing conditions of steel plates, steel plates are to be representative for each combination of thickness range and heat sample as follows:
(a) They include the intended maximum and minimum plate thicknesses

(b) Different heats are chosen for each thickness

Furthermore, the above-mentioned test plates are to include a fixed number of steel plates whose brittle crack arrest properties (i.e. brittle crack arrest test results) do not comply with **Table K3.40, Part K of the Rules for the Survey and Construction of Steel Ships**. Such a fixed number is to be at least one, but is not to exceed one quarter of all test plates. The manufacturing process of these test plates may be different (or intentionally altered from their approved manufacturing processes) from that of the arrest steels to which small-scale test methods are applied. It is, however, recommended that the strength grades of these test plates (i.e. test plates non-compliant with relevant requirements for brittle crack arrest properties) be similar to those of the arrest steels.

Where manufacturers have requested approval for only a single thickness, the thicknesses of test plates may be only of a single thickness. In such cases, at least four steel plates for each combination of thickness (single thickness) and heats (three different heats) are to be used, and the applicable thicknesses for small-scale tests are only the single thickness condition.

(4) Arrest steels used for manufacturing process approval tests (and approval test results) may also be used as the test plates specified in **1.3.3-1(3)**.

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

(6) Decreases in the total of indicated test plates may be accepted by the Society in the following cases:

(a) When manufacturers apply the same small-scale test procedure specification to multiple material grades, and manufacturing processes and mechanisms are adopted to ensure the brittle crack arrest properties of these different material grades are the same.

(b) When manufacturers apply small-scale test procedure specifications already approved by the Society for one or multiple material grades, and the manufacturer applies similar small-scale test procedure specification to the other similar material grades, and manufacturing processes and mechanisms are adopted to ensure the brittle crack arrest properties of these different material grades are same.

2 Brittle Crack Arrest Tests

(1) Brittle crack arrest tests for test plates are to be carried out in accordance **1.4.2** and **1.4.3, Chapter 1, Part 1**.

(2) Where brittle crack arrest tests are carried out for K_{ca} evaluations, K_{ca} values at specific temperatures are to be obtained in accordance with **1.3, Annex K3.12.3-1** "Guidance for Temperature Gradient ESSO Tests and Double Tensions Tests", **Part K of the Guidance for the Survey and Construction of Steel Ships**.

(3) Where brittle crack arrest tests are carried out for *CAT* evaluations, deterministic (actual) *CAT* values are to be obtained in accordance with **1.2.14, Annex K3.12.3-2** "Guidance for CAT Evaluation Tests", **Part K of the Guidance for the Survey and Construction of Steel Ships.**

3 Small-scale tests

(1) Small-scale tests are to be carried out in accordance with small-scale test procedure specifications approved for test plate.

(2) In general, test specimens for small-scale tests are to be taken with their longitudinal axes parallel to the final rolling directions of the test plates.

(3) Test specimens of small-scale tests are to be taken from specified positions in the plate thickness directions of test plates, as given in **1.3.2-1**.

1.3.4 Correlation Validation

1 A regression equation on the relationship between the brittle crack arrest properties obtained from brittle crack arrest tests and single or multiple small-scale test results is to be established. For brittle crack arrest properties, a specific temperature (e.g. $T_{Kca6000}$ in *BCA*6000, $T_{Kca8000}$ in

*BCA*8000 or *CAT*) or the K_{ca} value at −10 °C may be used.

2 The regression equation is to be verified to be suitable for predicting brittle crack arrest properties with sufficient accuracy. The correlation in brittle crack arrest properties between the calculated values from small-scale tests and brittle crack arrest test results is to be assured by using a value of twice the standard deviation (2σ). When using temperatures for brittle crack arrest properties, 2σ is not to be greater than 20 °C. In other cases (e.g. K_{ca} value at −10 °C), an upper limit of 2σ is to be established and agreed to by the Society.

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

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

n: Number of test plates

yi: Brittle crack arrest property obtained from brittle crack arrest test for one test plate

xi: Brittle crack arrest property estimated from small-scale tests for one test plate

1.3.5 Acceptance Criteria

1 Acceptance criteria for brittle crack arrest tests by small-scale tests are to be proposed by manufacturers based on regression equations assuring the correlation with brittle crack arrest properties required by **1.3.4** above. Such criteria are to be determined so that the regression equation can predict brittle crack arrest properties on the safe side in consideration of a scatter of brittle crack arrest property values predicted by the regression equation.

2 Unless otherwise agreed to by the Society, acceptance criteria for small-scale tests are to be determined by following procedures:

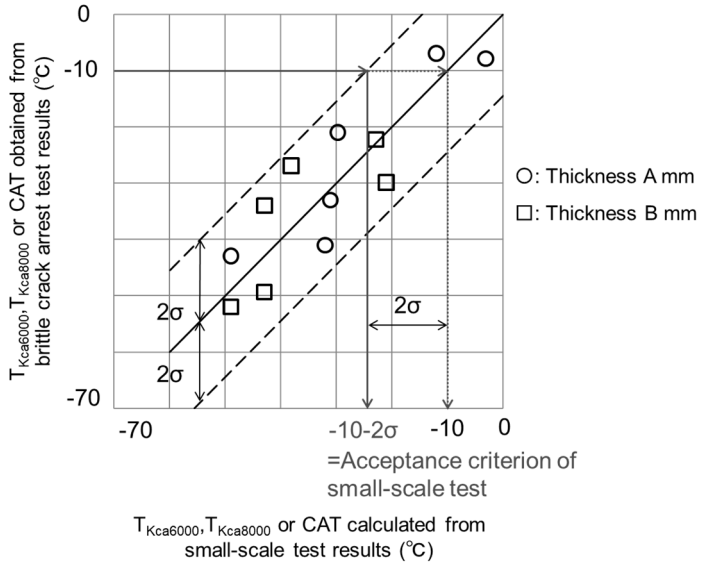
(1) Correlation by temperature

(a) The required temperature (see **Fig. 1.1-1**) is obtained by subtracting 2σ (°C) from the brittle crack arrest steel specification in **Table K3.41, Part K of the Rules for the Survey and Construction of Steel Ships** (i.e. −10 − 2σ (°C)), where 2σ is given in **1.3.4-2.** $T_{Kca6000}$ and $T_{Kca8000}$ in **Fig.1.1-1** are the temperatures at which K_{ca} equals 6,000 $N/mm^{3/2}$ and 8,000 $N/mm^{3/2}$, respectively.

(b) Temperature predicted from small-scale test results using the regression equation are to be no higher than the value of −10 − 2σ (°C).

Fig. 1.1-1 Example for Determination of Acceptance Criterion of Small-scale Test for Correlation by Means of Temperature

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



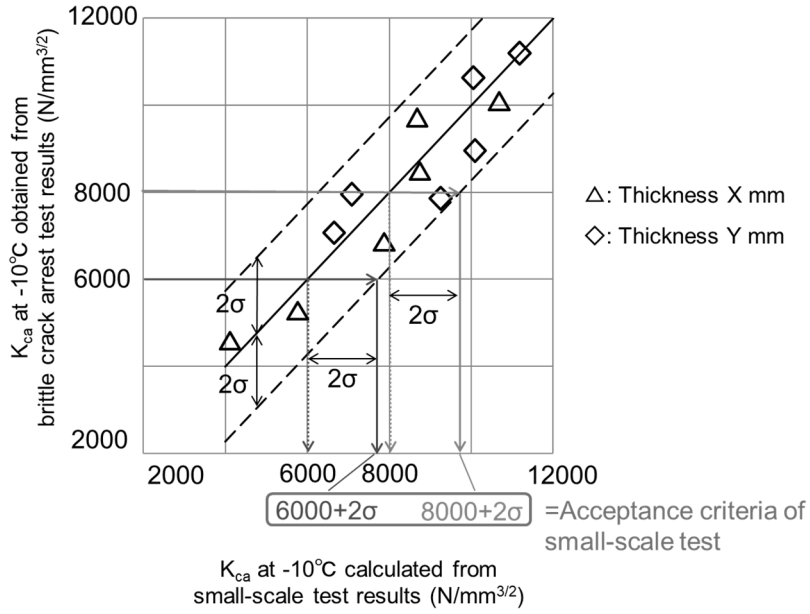
(2) Correlation by brittle crack arrest toughness (K_{ca})

(a) The required K_{ca} (see **Fig. 1.1-2**) is obtained by adding 2σ ($N/mm^{3/2}$) to the brittle crack arrest steel specification in **Table K3.41, Part K of the Rules for the Survey and Construction of Steel Ships** that is either 6,000 + 2σ ($N/mm^{3/2}$) for *BCA*6000 or 8,000 + 2σ ($N/mm^{3/2}$) for *BCA*8000, where 2σ is given in **1.3.4-2**.

(b) K_{ca} values predicted from small-scale test results using the regression equation are to be no smaller than the values of 6000 + 2σ ($N/mm^{3/2}$) for *BCA*6000 or 8000 + 2σ ($N/mm^{3/2}$) for *BCA*8000.

Fig. 1.1-2 Example for Determination of Acceptance Criteria of Small-scale Test for Correlation by Means of Brittle Crack Arrest Toughness (K_{ca})

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



1.4 Approval Tests

1.4.1 General

1 In order to confirm the validity of the submitted technical documents specified in **1.2.1**, approval tests are to be carried out.

2 Approval test plans are to be approved by the Society prior to testing.

3 Considering the contents of the submitted technical documents specified in **1.2.1**, the Society may require additional tests in the following cases:

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

(2) When the Society determines that the testing data obtained for setting the acceptance criteria of small-scale tests varies too widely, or that the data is clustered and produces biased correlation curves;

(3) When the Society determines that the validity of brittle crack arrest test results or small-scale test results for setting the acceptance criteria of small-scale tests is insufficient, or has some flaws during tests or in the test results;

(4) Other as deemed necessary by the Society.

1.4.2 Extent of the approval tests

Extent of the approval tests is to be in accordance with **1.4.1, Chapter 1, Part 1**.

1.4.3 Type of tests

1 Brittle crack arrest tests

(1) Brittle crack arrest tests are to be carried out in accordance with **1.4.2, Chapter 1, Part 1**.

(2) Where brittle crack arrest tests are carried out for K_{ca},evaluations, K_{ca} values at specific temperatures are to be obtained in accordance with **1.3, Annex K3.12.3-1** "Guidance for Temperature Gradient ESSO Tests and Double Tension Tests"**, Part K of the Guidance for the Survey and Construction of Steel Ships**.

(3) Where brittle crack arrest tests are carried out for *CAT* evaluations, deterministic *CAT* evaluation results are to be obtained in accordance with **1.2.14, Annex K3.12.3-2** "Guidance for CAT Evaluation Tests"**, Part K of the Guidance for the Survey and Construction of Steel Ships**.

2 Small-scale tests

Small-scale tests are to be carried out in accordance with **1.3.3-3**.

1.5 Results

1 Results of test items and procedures are to comply with test plan approved by the Society.

2 Manufacturers are to submit test reports to the Society in accordance with the following:

(1) For the brittle crack arrest test results K_{ca}, manufacturers are to submit brittle crack arrest test reports to the Society in accordance with **1.4.2, Chapter 1**.

(2) For the brittle crack arrest test *CAT* results, manufacturers are to submit brittle crack arrest test reports to the Society in accordance with **1.2.14, Annex K3.12.3-2** "Guidance for CAT Evaluation Tests"**, Part K of the Guidance for the Survey and Construction of Steel Ships**.

(3) For small-scale test results, manufacturers are to submit small-scale test reports to the Society in accordance with the examples of the formats to be used for submitted test reports specified in **1.2.1(2)**.

1.6 Approval

Upon satisfactory completion of surveys and tests, and satisfactory confirmation of the submitted technical documents, small-scale test procedure specification approval will be granted by the Society.

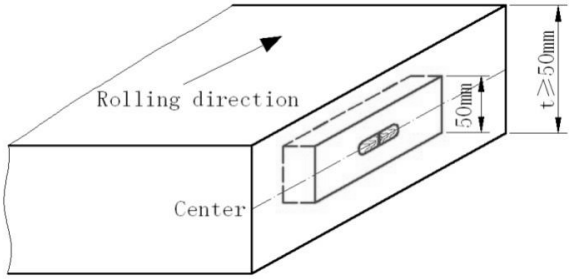
Table 1.1-1 Example of Small-scale Test Method Using *NRL* Drop Weight Test and *V*-notch Charpy Impact Test (Reference purposes only)

Test type:	*NRL* drop weight test and V-notch Charpy impact test
Standard:	*ASTM E* 208:2020 and *ISO* 148-1:2016
Sampling positions of test specimens:	*NRL* drop weight test: at surface *V* -notch Charpy impact test: 1/4 of thickness
Length direction of test specimen:	Parallel to the final rolling direction of test plate
Regression equation:	$T_{Kca} = \alpha \cdot (NDTT + 10) + \beta \cdot vTrs + 153(t-5)^{1/13} - 170.5$ T_{Kca}: Temperature at K_{ca} of 6,000N/mm3/2 or K_{ca} of 8,000 $N/mm^{3/2}$, (℃) *NDTT*: Nil-ductility transition temperature (℃) $_vT_{rs}$: Transition temperature of the absorbed energy (℃) t: thickness α and β (1): Constants
Notes:	(1) α and β are determined by comparing small-scale test results with brittle crack arrest test results.

Table 1.1-2 Example of Small-scale Test Method Using Pressed-notch Charpy Impact Test (Reference purposes only)

Test type:	Pressed-notch Charpy impact test
Standard:	Dimension, shape, introducing method of notch: Manufacturer's proposal Other: *ISO* 148-1:2016
Sampling position of test specimen:	1/2 of thickness
Length direction of test specimen:	Parallel to the final rolling direction of test plate
Regression equation:	$T_{Kca} = \alpha \ {}_pT_{E\gamma J} + \beta$ T_{Kca}: Temperature at K_{ca} of 6,000 $N/mm^{3/2}$ or K_{ca} of 8,000 $N/mm^{3/2}$ (℃) $_pT_{EvJ}$: Test temperature at absorbed energy of γ (*J*) (℃) α and β: Constants γ: Absorbed energy at brittle fracture surface ratio of δ (%) (*J*)
Notes:	(1) α, β, γ and δ are determined by comparing small-scale test results with brittle crack arrest test results.

Table 1.1-3 Example of Small-scale Test Method Using *NRL* Drop Weight Test (Side-section Drop Weight Test) (Reference purposes only)

Test type:	*NRL* drop weight test (side-section drop weight test)
Standard:	Dimension: P-2 type of *ASTM E* 208 2020
Sampling positions of test specimens:	1/2 of thickness and side-section 
Length direction of test specimen:	Parallel to the final rolling direction of the test plate
Regression equation:	$T_{Kca} = \alpha + \beta \cdot T_{NDT}^{side} + \gamma \cdot t^{1.5}$ T_{Kca}: Temperature at K_{ca} of 6,000 $N/mm^{3/2}$ or K_{ca} of 8,000 $N/mm^{3/2}$ (°C) T_{NDT}^{side}: Nil-ductility transition temperature obtained by side-section drop weight test (°C) t: thickness α, β and γ (1): Constants
Notes:	(1) α, β and γ are to be determined by comparing small-scale test results with brittle crack arrest test results.

Annex 1.1 has been renumbered to Annex 1.2.

Annex 1.~~1~~2 Corrosion Resistance Test for Cargo Oil Tanks