RULES FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

Part K Materials

RULES

2014 AMENDMENT NO.2

Rule No.78 19th December 2014

Resolved by Technical Committee on 29th July 2014

Approved by Board of Directors on 16th September 2014

Rule No.78 19th December 2014
AMENDMENT TO THE RULES FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

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

Part K MATERIALS

Chapter 3 ROLLED STEELS

3.2 Rolled Steel Plates for Boilers

3.2.3 Chemical Composition

Table K3.9 has been amended as follows.

Table K3.9 Chemical Composition

<table>
<tr><th rowspan="2">Grade</th><th rowspan="2">Thickness t (mm)</th><th colspan="13">Chemical composition (%)</th></tr>
<tr><th>C</th><th>Si</th><th>Mn</th><th>P</th><th>S</th><th>Mo</th><th>Cu</th><th>Ni</th><th>Cr</th><th>Nb</th><th>V</th><th>Ti</th><th>B</th></tr>
<tr><td rowspan="4">$KP42$</td><td>$t \le 25$</td><td>0.24 max.</td><td rowspan="18">0.15 ~ ~~0.30~~ 0.40</td><td rowspan="7">0.90 max.</td><td rowspan="18">~~0.035~~ 0.020 max.</td><td rowspan="18">~~0.040~~ 0.020 max.</td><td rowspan="10">0.12 max.</td><td rowspan="18">0.40 max.</td><td rowspan="18">0.40 max.</td><td rowspan="18">0.30 max.</td><td rowspan="18">0.020 max.</td><td rowspan="18">0.030 max.</td><td rowspan="18">0.030 max.</td><td rowspan="18">0.0010 max.</td></tr>
<tr><td>$25 < t \le 50$</td><td>0.27 max.</td></tr>
<tr><td>$50 < t \le 100$</td><td>0.29 max.</td></tr>
<tr><td>100~~50~~ $< t \le 200$</td><td>0.30 max.</td></tr>
<tr><td rowspan="3">$KP46$</td><td>$t \le 25$</td><td>0.28 max.</td></tr>
<tr><td>$25 < t \le 50$</td><td>0.31 max.</td></tr>
<tr><td>$50 < t \le 200$</td><td>0.33 max.</td></tr>
<tr><td rowspan="3">$KP49$</td><td>$t \le 25$</td><td>0.31 max.</td><td rowspan="3">1.20 max.</td></tr>
<tr><td>$25 < t \le 50$</td><td>0.33 max.</td></tr>
<tr><td>$50 < t \le 200$</td><td>0.35 max.</td></tr>
<tr><td rowspan="4">$KPA46$</td><td>$t \le 25$</td><td>0.18 max.</td><td rowspan="8">0.90 max.</td><td rowspan="8">0.45 ~ 0.60</td></tr>
<tr><td>$25 < t \le 50$</td><td>0.21 max.</td></tr>
<tr><td>$50 < t \le 100$</td><td>0.23 max.</td></tr>
<tr><td>$100 < t \le 150$</td><td>0.25 max.</td></tr>
<tr><td rowspan="4">$KPA49$</td><td>$t \le 25$</td><td>0.20 max.</td></tr>
<tr><td>$25 < t \le 50$</td><td>0.23 max.</td></tr>
<tr><td>$50 < t \le 100$</td><td>0.25 max.</td></tr>
<tr><td>$100 < t \le 150$</td><td>0.27 max.</td></tr>
</table>

Notes:

~~(1) For *KP* 46 with 25*mm* and over in thickness, carbon content and manganese content may be 0.3% or less and 1.00% or less respectively.~~

(~~2~~1) For *KP*42, *KP*46 and *KP* 49, ~~carbon content and manganese content may be 0.3% or less and 1.15% or less respectively~~ manganese content may be increased by 0.06% for each 0.01% decrease in carbon content. However, the upper limit of manganese content is to be 1.50%

(2) For *KP*42, *KP*46 and *KP* 49, the combined total content of copper, nickel, chromium and molybdenum is not to exceed 1.00%; In addition, the combined total content of chromium and molybdenum is not to exceed 0.32%.

3.2.4 Heat Treatment

Sub-paragraph -3 has been amended as follows.

3 For steel plates to which stress relieving is required after welding or stress relieving is applied by the purchaser once or several times repeatedly during their working process, instructions regarding both ~~of that effect~~ heat treatment conditions and frequency are to be given by the purchaser when the order is placed. ~~is to be given at the time when they are placed for an order~~. ~~In case where the procedure of stress relieving is not specified by the purchaser, a heat treatment is to be applied for the test coupons by heating them slowly and uniformly to the temperature of 600°C~~

~~to 650°C, holding at that temperature for a period of over one hour per 25*mm* of thickness, and then, to be cooled to 300°C in the furnace before exposure in a still atmosphere.~~

3.2.6 Selection of Test Samples

Sub-paragraph -2 has been amended as follows.

1 For the steel plates which are not to be heat treated, one test sample is to be taken from each plate as rolled directly from one slab or ingot ; for the plates which are to be heat treated, one test sample is to be taken from every similarly heat treated plate as rolled directly from one slab or ingot.

2 Where the plates specified in **-1** are to be stress-relieved as specified in **3.2.4-3**, the conditions and frequency of the heat treatment for the stress-relieving of any ~~the~~ test samples are to be ~~heat treated~~ in accordance with ~~the intended stress-relieving~~ purchaser instructions.

3.3 Rolled Steel Plates for Pressure Vessels

3.3.3 Chemical Composition

Table K3.12 has been amended as follows.

Table K3.12 Chemical Composition

Grade	Chemical composition (%)						Carbon equivalent $C_{eq}(JIS)$ (%)(1)(2)				
							Quenched and tempered		*TMCP*		
	C		*Si*	*Mn*	*P*	*S*	50*mm* and under in thickness	Over 50*mm* and up to 75*mm* in thickness	50 *mm* and under in thickness	Over 50 *mm* and up to 100 *mm* in thickness	Over 100 *mm* and up to 150 *mm* in thickness
*KPV*24	100*mm* and under in thickness	0.18 max	~~0.15-~~ 0.35 max.	1.40 max.	0.030 max.	0.030 max.	—	—	—	—	—
	Over 100*mm* in thickness	0.20 max									
*KPV*32	0.18 max.		~~0.15-~~ 0.55 max.	1.60 max.			—	—	0.39 max.	0.41 max.	0.43 max.
*KPV*36	0.20 max.		~~0.15-~~ 0.55 max.				—	—	0.40 max.	0.42 max.	0.44 max.
*KPV*42	0.18 max.		~~0.15-~~ 0.75 max.				—	—	0.43 max.	0.45 max.	—
*KPV*46	0.18 max.		~~0.15-~~ 0.75 max.				~~0.43~~ 0.44 max.	~~0.45~~ 0.46 max.	—	—	—
*KPV*50	0.18 max.		~~0.15-~~ 0.75 max.				~~0.44~~ 0.45 max.	~~0.46~~ 0.47 max.	—	—	—

Notes:

(1) The carbon equivalent $C_{eq}(JIS)$ is to be obtained using ladle analysis from the following formula, regardless of the requirements in **1.5.2-2(6)**.

$$C_{eq}(JIS) = C + \frac{Mn}{6} + \frac{Si}{24} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{14} \ (\%)$$

(2) Carbon equivalent $C_{eq}(JIS)$ is not specified where plates are as-rolled, controlled-rolled or normalized.

3.3.6 Selection of Test Samples

Sub-paragraph -2 has been amended as follows.

1 For the steel plates which are not to be heat treated, one test sample is to be taken from each plate as rolled directly from one slab or ingot; for the steel plates which are to be heat treated, one test sample is to be taken from every similar heat treated plates as rolled directly from one slab or ingot.
2 Where the plates specified in **-1** are to be stress-relieved as specified in **3.3.4-5**, the conditions and frequency of the heat treatment for the stress-relieving of any test samples are to be ~~heat treated~~ in accordance with ~~the intended stress-relieving~~ purchaser instructions.

3.12 Additional Requirements for Brittle Crack Arrest Properties

3.12.2 Brittle Crack Arrest Properties etc.

Table K3.38 has been amended as follows.

Table K3.38 Brittle Crack Arrest Properties

Kinds of Steels			classification	Temperature gradient *ESSO* tests or double tension tests	
				Evaluation Temperature (°C)	~~Brittle Crack~~ Arrest Toughness Value Kca ($N/mm^{\cancel{1.5}\,3/2}$)
Rolled Steels for Hull	*KE*, *KE*32, *KE*36, *KE*40, *KE*47	*KF*32, *KF*36, *KF*40,	*A*400	-10	min. 4000
			*A*500	-10	min. 5000
			*A*600	-10	min. 6000

Note:
In cases where deemed appropriate by the Society, a new classification division for those properties exceeding *A*600 may be permitted.

Paragraph 3.12.5 has been amended as follows.

3.12.5 Additional Tests before Rejection

1 Where the result of temperature gradient *ESSO* tests or double tension tests fails to meet the requirements, those tests may be carried out additionally on two more test specimens. In this case, the judgment of acceptance is to be made on the ~~Brittle Crack~~ Arrest Toughness Value K_{ca} of all four test specimens.

EFFECTIVE DATE AND APPLICATION

1. The effective date of the amendments is 19 December 2014.
2. Notwithstanding the amendments to the Rules, the current requirements may apply to materials other than those for which the application for survey is submitted to the Society on or after the effective date.

GUIDANCE FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

Part K Materials

GUIDANCE

2014 AMENDMENT NO.1

Notice No.68 19th December 2014
Resolved by Technical Committee on 29th July 2014

Notice No.68　　19th December 2014
AMENDMENT TO THE GUIDANCE FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

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

Part K　MATERIALS

K3　ROLLED STEELS

K3.2　Rolled Steel Plates for Boilers

Paragraph K3.2.6 has been amended as follows.

K3.2.6　Selection of Test Samples

Where the purchasers carry out normalizing specified in **3.2.4-2, Part K of the Rules** at their factories, ~~selections of~~ test samples are to comply with the following requirements:

(1) The manufacturer is to carry out normalizing of the test sample in accordance with ~~conforming to the instructions by the~~ purchaser instructions regarding heat treatment conditions and frequency. W~~w~~here no instructions have been given by the purchaser, the manufacturer may carry out normalizing as considered preferable. In this case, the manufacturer is to inform the purchaser the conditions of normalizing which had been carried out.

~~(2) The test samples is taken from the steel plates normalized at purchasers factory or normalized together with the steel plates simultaneously.~~

(~~3~~2) The mechanical properties obtained by the test specimens specified in **(1)** ~~**and (2)**~~ above are to comply with the provisions in **Table K3.10, Part K of the Rules**.

K3.3　Rolled Steel Plates for Pressure Vessels

Paragraph K3.3.4 has been amended as follows.

K3.3.4　Heat Treatment

Normalizing or quenching and tempering of the steel plates specified in **3.3.4-~~2~~4, Part K of the Rules** may be carried out by the purchasers at their own factories. In this case, test ~~specimens~~ samples are to be taken in accordance with the requirements of **K3.3.6~~-1~~**.

Paragraph K3.3.6 has been amended as follows.

K3.3.6　Selection of Test Samples

~~**1**~~ Where the purchasers carry out normalizing or quenching and tempering specified in **3.3.4-~~2~~4, Part K of the Rules** at their factories, ~~selection of~~ test samples ~~is~~ are to comply with the following requirements: ~~specified in **(1) and (2)** of **K3.2.6**~~

(1) The manufacturer is to carry out normalizing or quenching and tempering of the test sample in accordance with purchaser instructions regarding heat treatment conditions and frequency. Where no instructions have been given by the purchaser, the manufacturer may carry out normalizing or quenching and tempering as considered preferable. In this case, the manufacturer is to inform the purchaser the conditions of normalizing or quenching and

tempering which had been carried out.

~~2~~(2) The mechanical properties obtained by the test specimens specified in **(1)** above are to comply with the requirements specified in **Table K3.13, Part K of the Rules.**

Paragraph K3.3.11 has been amended as follows.

K3.3.11 Marking

The markings related to the heat treatments of the steel plates ~~provided~~ specified in **K3.3.6** are to be "*TN*" ~~(showing~~ in cases where normalizing is carried out for test samples only~~)~~ or "*TQ*"in cases where quenching and tempering are carried out for test samples only.

K3.12 Additional Requirements for Brittle Crack Arrest Properties

K3.12.2 Brittle Crack Arrest Properties etc.

Sub-paragraph -1 has been amended as follows.

1 In **3.12.2-1, Part K of the Rules**, "the discretion of the Society" can be regarded as **Annex K3.12.2-1** "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 **3.12.4-1, Part K of the Rules**, notwithstanding the requirements in **1.2.11, Annex K3.12.2-1**.

Title of Annex K3.12.2-1 has been amended as follows.

Annex K3.12.2-1 GUIDANCE FOR TEMPERATURE GRADIENT ESSO TESTS AND DOUBLE TENSION TESTS

Sections 1.1 to 1.9 have been deleted.

~~1.1 Scope~~

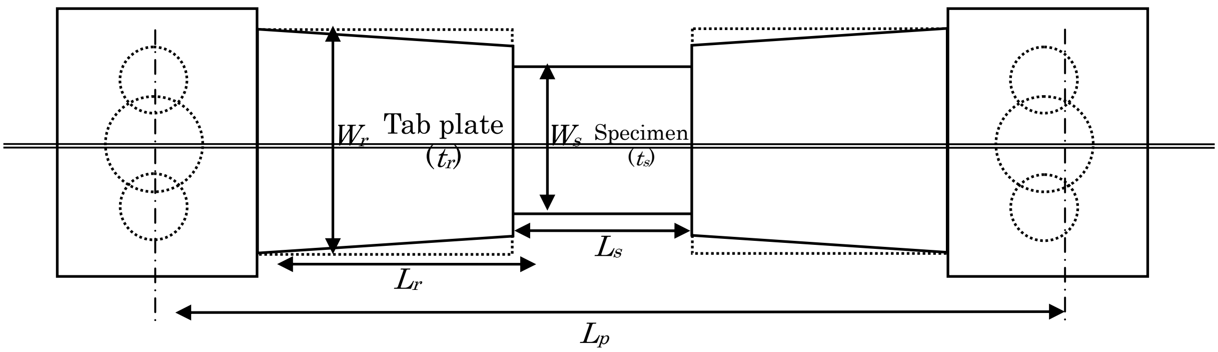
~~This test method is used to estimate the brittle crack arrest toughness value~~ $\cancel{K_{ca}}$ ~~of rolled steel plates for hull of thicknesses of 100~~ ~~*mm*~~ ~~or less. The brittle crack arrest toughness value~~ $\cancel{K_{ca}}$ ~~of rolled steel plates for hull of thicknesses more than 100~~~~*mm*~~ ~~is left to the discretion of the Society.~~

~~1.2 Symbols~~

~~Table 1 Symbols used and their meanings~~

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

~~Fig. 1 Conceptual view of test specimen, tab, and load jig~~



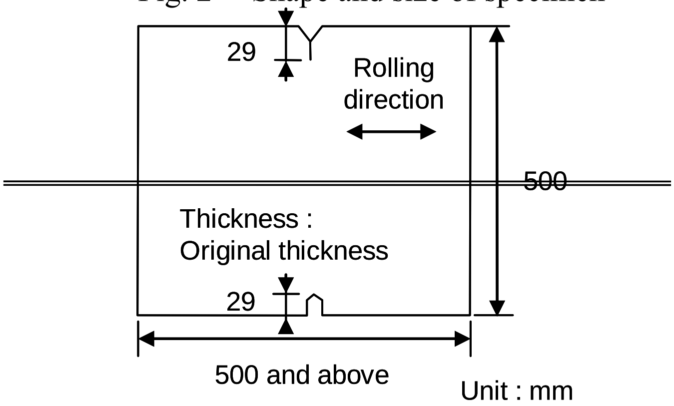
~~1.3 Purpose~~

~~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 toughness value~~ $\cancel{K_{ca}}$~~.~~

~~1.4 Standard test specimen~~

~~**1** **Fig. 2** shows the shape and size of the standard test specimen.~~

~~Fig. 2 Shape and size of specimen~~



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

~~Table 2 Thickness and width of test specimen~~

~~Thickness, t_S~~	~~100mm and below~~
~~Width of test specimen, W_S~~	~~500mm~~

~~Note:~~

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

~~**3** The test specimens are to be taken from the same steel plate.~~
~~**4** Test specimens are to be taken in such a way that the axial direction of the load is parallel to the rolling direction of the steel plate.~~
~~**5** The thickness of the test specimen is to be the same as the thickness of the steel plate.~~

~~1.5 Test equipment~~

~~The test equipment to be used is to consist of pin load type hydraulic test equipment capable of tensile tests. 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. Drop weight type or air gun type impact equipment may be used for the impact energy required for generating brittle cracks. 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.~~

~~1.6 Test preparations~~

~~**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 3**.~~

~~Table 3 Allowable dimensions of tab plate~~

	~~Thickness, t_p~~	~~Width, W_p~~
~~Dimensions of tab plate~~	~~$0.8\,t_S{}^{(1)(2)} \leqq t_p \leqq 1.5\,t_S$~~	~~$W_S{}^{(3)} \leqq W_p \leqq 2\,W_S$~~

~~Note:~~

~~(1) t_S: Thickness of test specimen~~

~~(2) 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 0.8~~$\cancel{t_s}$~~.~~

~~(3) W_s: Thickness of test specimen~~

~~**2** Thermocouples are to be fitted at 50 *mm* pitch on the notch extension line of the test specimen.~~
~~**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.~~
~~**4** If dynamic measurements are necessary, strain gauges and crack gauges are to be fitted at specific locations.~~
~~**5** The test specimen is to be fixed to the testing machine together with the tab plate after welding and the pin load jig.~~
~~**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.~~

~~1.7 Test method~~

~~**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.~~
~~**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.~~
~~**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~~ $\cancel{0.3W_s}$ ~~to~~ $\cancel{0.7W_s}$ ~~at the central part of the test specimen.~~
~~**4** When the specific temperature gradient is reached, the temperature is to be maintained for more than 10 minutes, after which the specified test load may then be applied.~~
~~**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.~~
~~**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.~~
~~**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.~~

~~1.8 Test results~~

~~**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.~~
~~**2** From the results of thermocouple measurement, the temperature distribution curve is to be plotted, and the arrest crack temperature is to be measured corresponding to the arrest crack length.~~
~~**3** The brittle crack arrest toughness value (~~$\cancel{K_{ca}}$ ~~value) of each test is to be determined by using the following formula:~~

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

~~1.9 Report~~

~~**1** The following items are to be report:~~

~~(1) Testing machine specifications; testing machine capacity, distance between pins (L_P)~~

~~(2) Load jig dimensions; tab plate thickness (t_r), tab plate width (W_r), test specimen length including tab plate (L_S+2L_r)~~

~~(3) Test specimen dimensions; plate thickness (t_S); test specimen width (W_S) and length (L_S)~~

~~(4) Test conditions; preload stress, test stress, temperature distribution (figure or table); impact energy~~

~~(5) Test results; crack arrest length (a_a), temperature gradient at arrest position, brittle crack arrest toughness (K_{ca})~~

~~(6) Dynamic measurement results (if measurement is carried out); crack growth rate, strain change~~

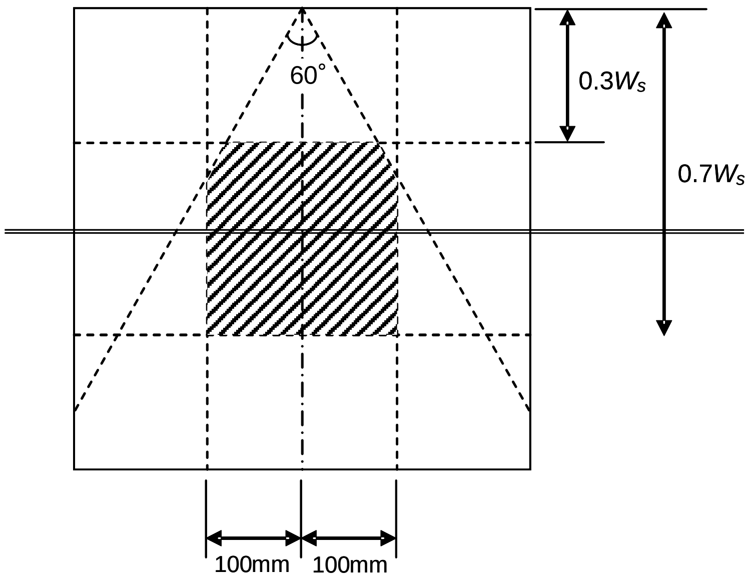
~~(7) Test specimen photos; fracture route, fractured surface~~

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

~~(1) The brittle crack arrest position is to be in the range of the hatched part shown in **Fig. 3**. 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.~~

~~(2) The brittle crack is not to have a distinct crack bifurcation while it propagates.~~

~~Fig. 3 Necessary conditions of arrest crack position~~



~~**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.~~

Sections 1.1 to 1.3 have been added as follows.

1.1 General

1.1.1 Application

The requirements in this Guidance apply to rolled steel plates for hulls of thicknesses of 100 *mm* or less. Rolled steel plates having thickness exceeding 100 *mm* are to the discretion of the 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_p	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_{br}	mm	Coordinate of longest branch crack tip in width direction
y_a	mm	Coordinate of main crack tip in stress loading direction
y_{br}	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

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.

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.

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.

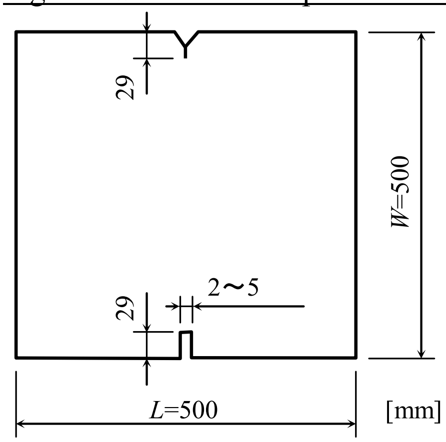
2 Wedge is to be hard enough to prevent significant plastic deformation caused by impact.

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	6 $mm \leq t \leq$ 100 mm
Test specimen width, W	350 $mm \leq W \leq$ 1000 mm
Test specimen width/test specimen thickness, W / t	$W / t \geq 5$

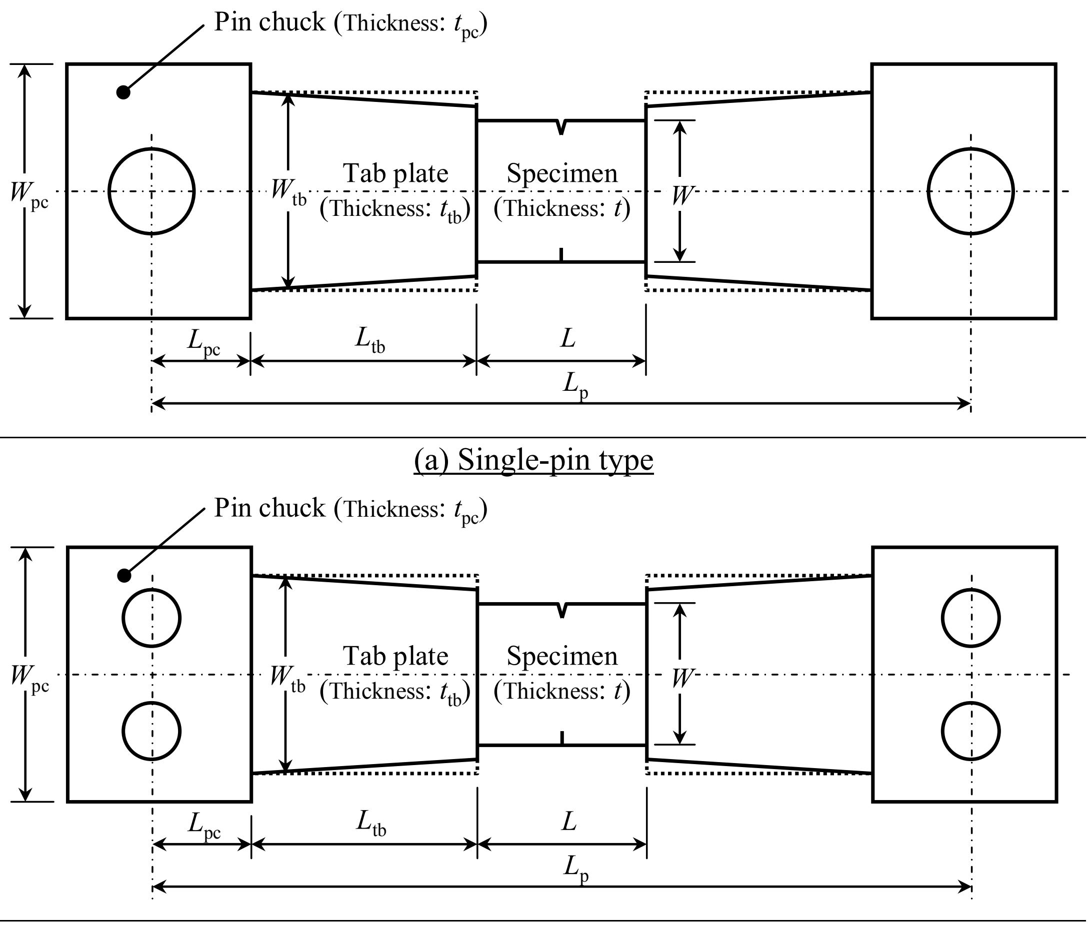
Note:

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**.

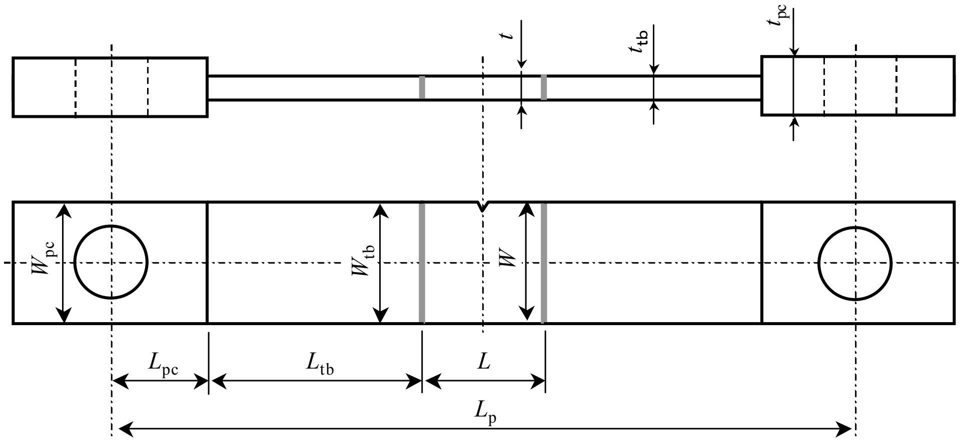
Fig. 2 Definitions of dimensions of tab plates and pin chucks



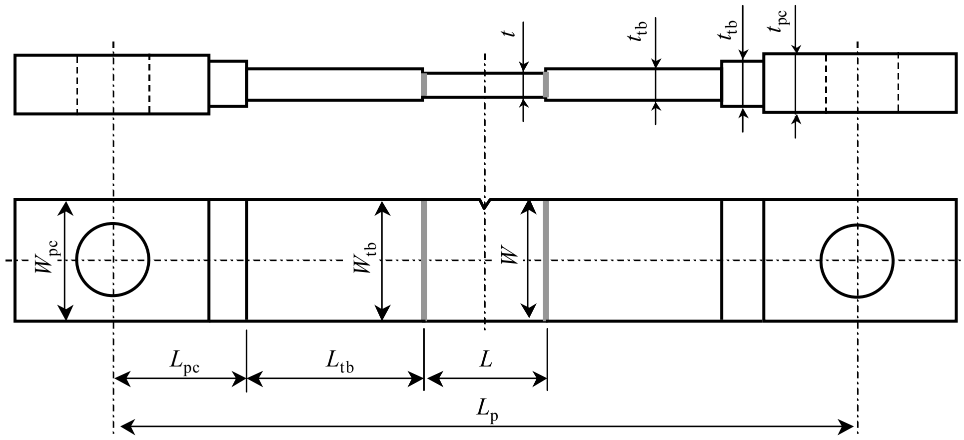
(b) Double-pin type

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

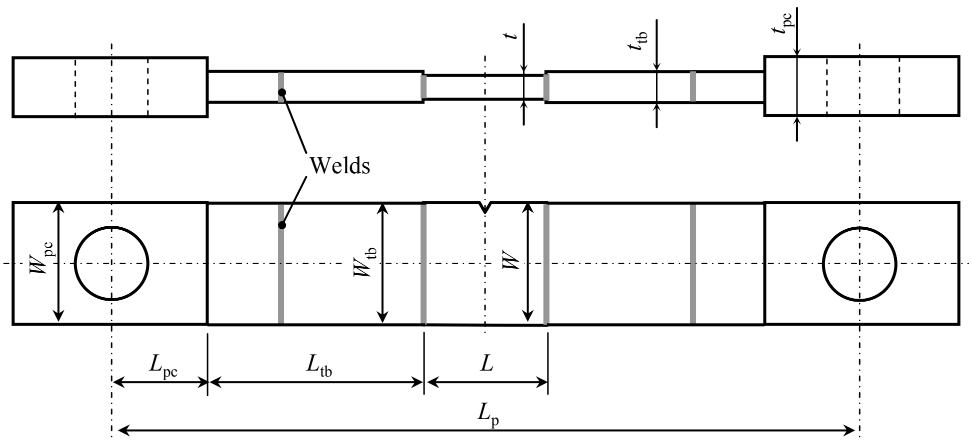
Fig. 3 Standard dimensions of tab plates and pin chucks



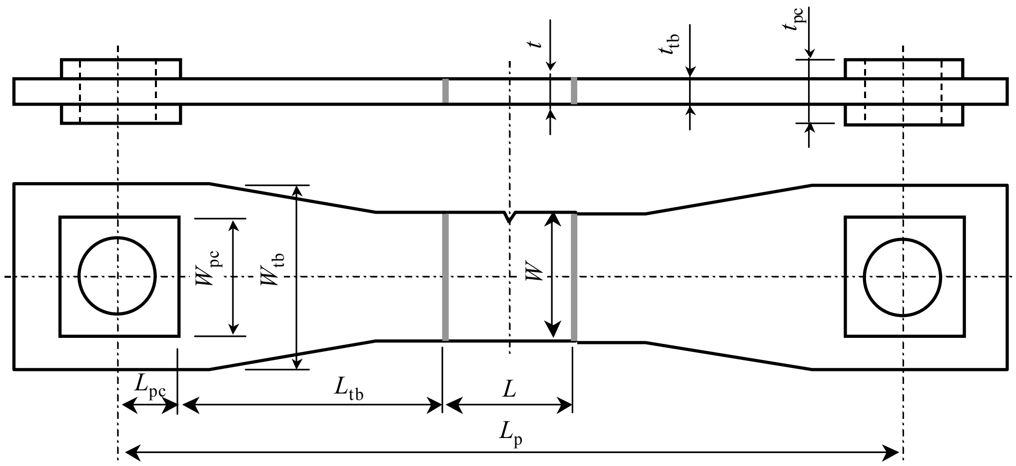
(a) Example 1



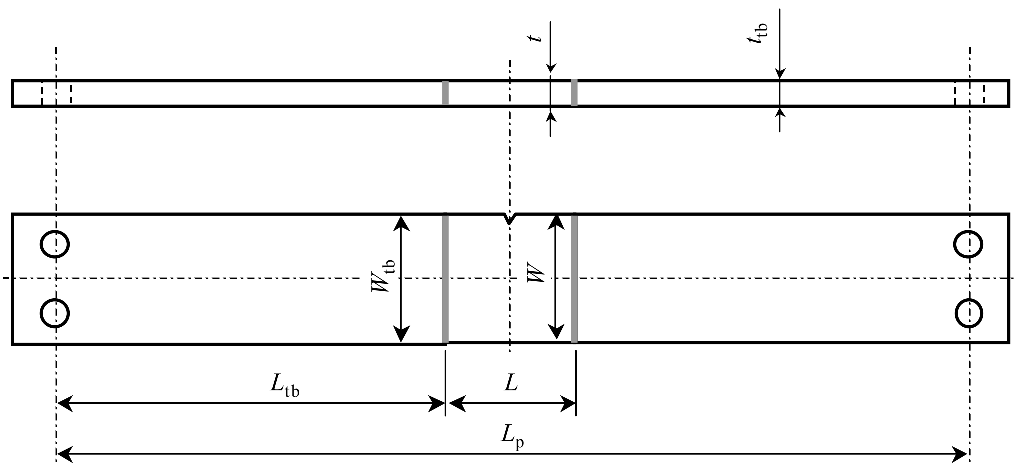
(b) Example 2



(c) Example 3



(d) Example 4



(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_t) / 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 (e), Example 5**, it is obtained by setting $L_{pc} = 0$.

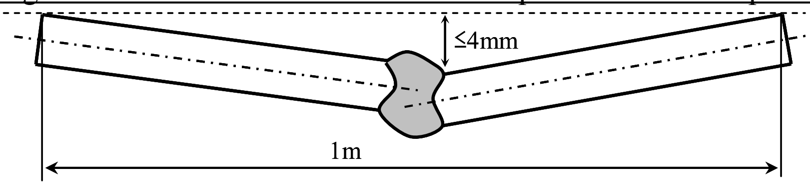
$$L_p = L + 2L_{tb} + 2L_{pc}$$

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.

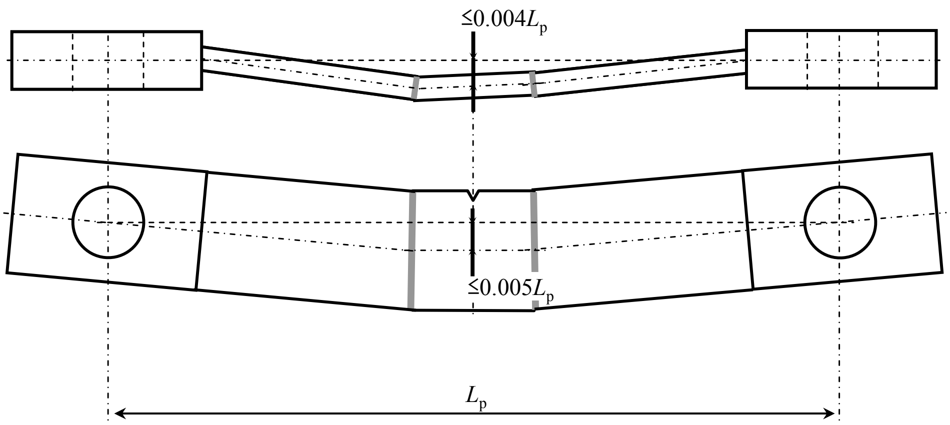
2 As shown in **Fig. 4**, the flatness (angular distortion and linear misalignment) of the welds between test specimens and tab plates are to be 4 *mm* or less per *meter*. In the case of preloading, however, it is acceptable if the value after preloading satisfies this condition.

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 0.3W to 0.7W. 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＋0.1t [*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., 0.5W), 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_i, to thickness, t, ratios satisfy following formula:

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

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:

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

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. If no crack is initiated, 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 achive this, the test specimen may be heated using a gas burner or the like. If it is necessaryeded 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)**:

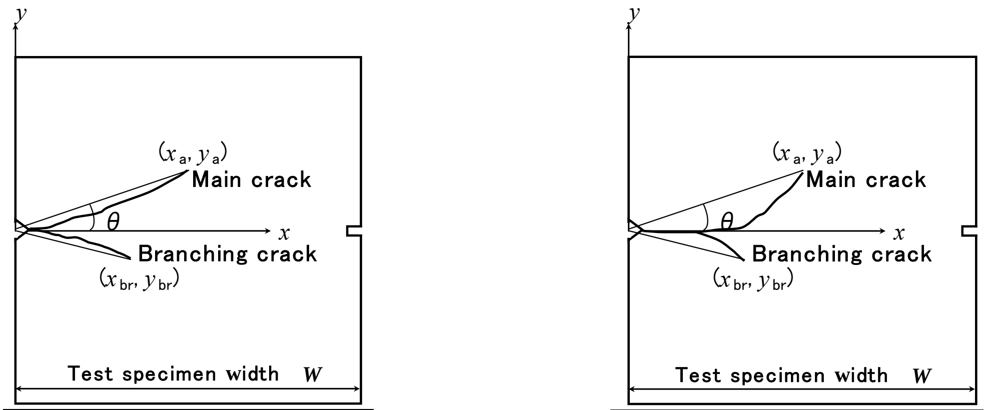
(1) Take photographs of fracture surfaces and propagation path.

(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. 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_{br}, y_{br}) 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.

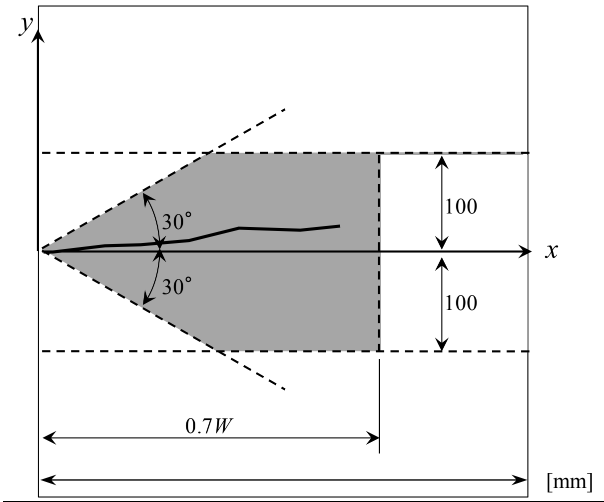
1.2.9 Determination of arrest toughness value

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) $\left(\frac{a}{L_p}\right) \leqq 0.15$

(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 $x = 0.5W$, $y = \pm 100\ mm$ falls within ± 2.5°C at $x = 0.5W$, and $y = 0$.

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

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

2 Impact energy, E_i, 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.

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

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

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

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.

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

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

1.2.10 Reporting

The following items are to be reported. An example of the format to be used for reports is shown in **Form 1-1**.

(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 Method for obtaining arrest toughness value at a specific temperature

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

1.3 Temperature gradient double tension tests

1.3.1 General

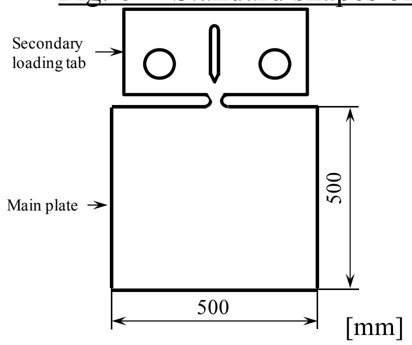
1 The requirements in this section are related to the evaluation of brittle crack arrest toughness through the use of temperature gradient double tension tests.

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

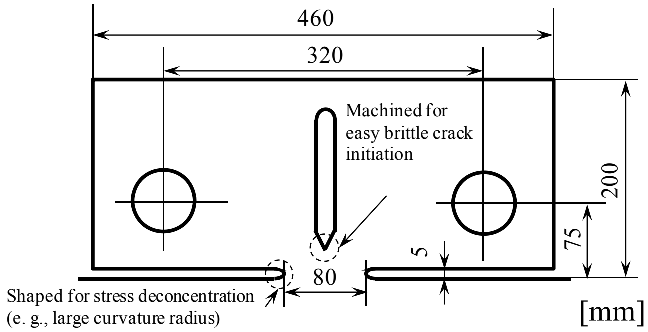
1.3.2 Test specimen shapes

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 suspens 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.

Form 1-1

Item	Details		Symbol	Conditions/ Results	Unit	Valid/ Invalid
(1) Test material	Steel type		–		–	–
	Yield stress at room temperature		σ_{Y0}		N/mm^2	–
(2) Test equipment	Testing machine capacity		–		MN	–
(3) Test specimen dimensions	Thickness		t		mm	
	Width		W		mm	
	Length		L		mm	
	Angular distortion + linear misalignment		–		mm/m	
(4) Integrated specimen dimensions	Tab plate thickness		t_{tb}		mm	
	Tab plate width		W_{tb}		mm	
	Test specimen length including a tab plate		$L + L_{tb}$		mm	
	Distance between loading pins		L_p		mm	
(5) Test conditions	Applied load		F		MN	
	Applied stress		σ		N/mm^2	
	Temperature gradient		–		°C /mm	
	Impact energy		E_i		J	
	Ratio of impact energy to strain energy stored in the integrated specimen		$E_i/(E_s+E_t)$		–	
(6) Test results	Judgment on crack propagation/arrest	Crack length	a		mm	
		Presence/absence of crack branching	–		–	–
		Ratio of branch crack length to main crack	x_{br}/x_a		–	
		Main crack angle	θ		degree (°)	
		Presence/absence of crack re-initiation	–		–	
		Temperature at the crack arrest position	T		°C	
	Arrest toughness value		K_{ca}		$N/mm^{3/2}$	
(7) Temperature distribution at the moment of impact	Temperature measurement position		–	Attached	–	–
	Temperature at each temperature measurement position		–	Attached	°C	–
	Temperature distribution curve		–	Attached	–	
(8) Test specimen photographs	Crack propagation path		–	Attached	–	
	Brittle crack fracture surface (both sides)		–	Attached	–	
(9) Dynamic measurement results	History of crack propagation velocity		–	Attached	–	
	Strain change at pin chucks		–	Attached	–	

Annex K5.1.11(3) GUIDANCE FOR REPAIRING OF HULL STEEL CASTINGS

1.2 Methods of Repairing

Sub-paragraph -2(3) has been amended as follows.

(3) Preheating

(a) In cases where the carbon equivalent $\underline{C_{eq}(JIS)}$ of the steel castings exceeds 0.44%, the portions of repair welding and their vicinity are to be preheated to a temperature higher than 200 °C. In this case, the carbon equivalent $\underline{C_{eq}(JIS)}$ is to be calculated by the following formula

$$C_{eq}\underline{(JIS)}\cancel{(\%)} = C + \frac{Mn}{6} + \frac{Si}{24} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{14} \quad \underline{(\%)}$$

(b) Even in case where carbon equivalent $\underline{C_{eq}(JIS)}$ is 0.44% or less, preheating may be required taking into account the shape and size of the steel castings.

Sub-paragraph -2(5)(a) has been amended as follows.

(a) Post weld heat treatment may be exempted in the following cases, provided that the carbon equivalent $\underline{C_{eq}(JIS)}$ does not exceed 0.44%.

i) In case where the depth of chipping after the removal of defects is not more than 25 *mm* (or 20% of the thickness, whichever is smaller) and the length is not more than 200 *mm*.

ii) In cases where the depth of chipping after the removal of defects is not more than 15 *mm* and also the area is not more than 250,000 mm^2.

EFFECTIVE DATE AND APPLICATION

1. The effective date of the amendments is 19 December 2014.

2. Notwithstanding the amendments to the Guidance, the current requirements may apply to materials other than those for which the application for survey is submitted to the Society on or after the effective date.