RUSSIAN MARITIME REGISTER OF SHIPPING

**CIRCULAR LETTER** **No. 314-01-1485c** dated 17.12.2020

Re:
amendments to the Rules for the Classification and Construction of Sea-Going Ships in connection with coming into force of IACS Unified Requirement (UR) W31 (Rev.2 Dec 2019)

Item(s) of supervision:
ships under construction

Entry-into-force date: **01.01.2021** ~~Valid till:~~ ~~Validity period extended till:~~

~~Cancels / amends / adds Circular Letter No.~~ ~~dated~~

Number of pages: 1 + 34

Appendices:
Appendix 1: information on amendments introduced by the Circular Letter
Appendix 2: text of amendments to Parts XIII "Materials" and XIV "Welding"

Director General Konstantin G. Palnikov

Text of CL:
We hereby inform that the Rules for the Classification and Construction of Sea-Going Ships, at their re-publication in 2021, shall be amended as specified in the Appendices to the Circular Letter.

It is necessary to do the following:
1. Bring the content of the Circular Letter to the notice of the RS surveyors, interested organizations and persons in the area of the RS Branch Offices' activity.
2. Apply the provisions of the Circular Letter during review and approval of the technical documentation on ships contracted for construction or conversion on or after 01.01.2021, in the absence of a contract — on ships, the keels of which are laid or which are at a similar stage of construction on or after 01.01.2021, as well as during review and approval of the technical documentation on ships, the delivery of which is on or after 01.01.2021.

List of the amended and/or introduced paras/chapters/sections:
Part XIII: para 2.2.11, Chapters 3.19 and 3.20
Part XIV: paras 2.12.6, 2.12.7, 4.7.1.1 and 4.7.1.3 and Tables 4.7.2.4, 4.7.3.3 and 4.7.4.2

Person in charge: Maxim E. Yurkov, Alexander S. Tumanov 314 +7 (812) 312-85-72
"Thesis" System No. 20-221186

**Information on amendments to Part XIII, introduced by the Circular Letter
(for inclusion in the Revision History to the RS Publication)**

| Nos. | Amended paras/chapters/sections | Information on amendments | Number and date of the Circular Letter | Entry-into-force date |
|---|---|---|---|---|
| 1 | Part XIII, para 2.2.11 | New para with requirements for test method for arrest brittle crack toughness of steel plates with thickness from 50 to 100 mm has been introduced considering IACS UR W31 (Rev.2 Dec 2019) | 314-01-1485c of 17.12.2020 | 01.01.2021 |
| 2 | Part XIII, Chapter 3.19 | The text of the Chapter has been completely amended considering IACS UR W31 (Rev.2 Dec 2019) | 314-01-1485c of 17.12.2020 | 01.01.2021 |
| 3 | Part XIII, Chapter 3.20 | The Chapter has been deleted considering IACS UR W31 (Rev.2 Dec 2019) | 314-01-1485c of 17.12.2020 | 01.01.2021 |
| 4 | Part XIV, paras 2.12.6 and 2.12.7 | New paras with the requirements for YP47 and BCA steels welding have been introduced considering IACS UR W31 (Rev.2 Dec 2019) | 314-01-1485c of 17.12.2020 | 01.01.2021 |
| 5 | Part XIV, para 4.7.1.1 | Requirements for YP47 and BCA steels have been specified considering IACS UR W31 (Rev.2 Dec 2019) | 314-01-1485c of 17.12.2020 | 01.01.2021 |
| 6 | Part XIV, para 4.7.1.3 | Requirements for YP47 and BCA steels have been specified considering IACS UR W31 (Rev.2 Dec 2019) | 314-01-1485c of 17.12.2020 | 01.01.2021 |
| 7 | Part XIV, Table 4.7.2.4 | New grade of consumables has been added considering IACS UR W31 (Rev.2 Dec 2019) | 314-01-1485c of 17.12.2020 | 01.01.2021 |
| 8 | Part XIV, Table 4.7.3.3 | New grade of consumables has been added considering IACS UR W31 (Rev.2 Dec 2019) | 314-01-1485c of 17.12.2020 | 01.01.2021 |
| 9 | Part XIV, Table 4.7.4.2 | New grade of consumables has been added considering IACS UR W31 (Rev.2 Dec 2019) | 314-01-1485c of 17.12.2020 | 01.01.2021 |

# RULES FOR THE CLASSIFICATION AND CONSTRUCTION OF SEA-GOING SHIPS, 2020,

# ND No. 2-020101-124-E

## PART XIII. MATERIALS

1 **New para 2.2.11** is introduced reading as follows:

"**2.2.11 Test method (algorithm) for properties of steel plate arrest brittle crack with thickness from 50 to 100 mm.**

**2.2.11.1** Test Method for Brittle Crack Arrest Toughness, $K_{ca}$.

Setting a temperature gradient in the width direction of a test specimen, and applying uniform stress in the transverse crack propagation direction to the test specimen to determine $K_{ca}$, the test specimen shall be struck to initiate a brittle crack from the mechanical notch at the side of the test specimen (temperature gradient type arrest testing).

Using the stress intensity factor, the brittle crack arrest toughness, $K_{ca}$, shall be calculated from the applied stress and the arrest crack length. This value is the brittle crack arrest toughness at the temperature of the point of crack arrest (arrest temperature). To obtain $K_{ca}$ at a specific temperature followed by the necessary evaluation, the method specified in 2.2.11.2 may be used.

As a method for initiating a brittle crack, a secondary loading mechanism may also be used in accordance with 2.2.11.3.

**2.2.11.1.** Scope of application.

Requirements of 2.2.11.1 apply to the test method for brittle crack arrest toughness (i.e. $K_{ca}$) of steel using fracture mechanics parameter. They are applicable to hull structural steels with the thickness over 50mm and not greater than 100mm in accordance with 3.2 or 3.19.

**2.2.11.1.2** Symbols and their significance.

The symbols and their significance used in 2.2.11.1 are shown in Table 2.2.11.1.2.

Table 2.2.11.1.2

| Symbol | Unit | Significance |
|---|---|---|
| $a$ | mm | Crack length or arrest crack length |
| $E$ | N/mm$^2$ | Modulus of longitudinal elasticity |
| $E_i$ | J | Impact energy |
| $E_s$ | J | Strain energy stored in a test specimen |
| $E_t$ | J | Total strain energy stored in tab plates and pin chucks |
| $F$ | MN | Applied load |
| $K$ | N/mm$^{3/2}$ | Stress intensity factor |
| $K_{ca}$ | N/mm$^{3/2}$ | Arrest toughness. Crack resistance parameter *CTOD* is the critical value of the stress intensity factor being the crack arrest, running along the brittle mechanism in the specific crack material. |
| $L$ | mm | Test specimen length |
| $L_p$ | mm | Distance between the loading pins |
| $L_{pc}$ | mm | Pin chuck length |
| $L_{tb}$ | mm | Tab plate length |
| $T$ | °C | Temperature or arrest temperature |
| $t$ | mm | Test specimen thickness |
| $t_{tb}$ | mm | Tab plate thickness |
| $t_{pc}$ | mm | Pin chuck thickness |
| $W$ | mm | Test specimen width |
| $W_{tb}$ | mm | Tab plate width |
| $W_{pc}$ | mm | Pin chuck width |
| $x_a$ | mm | Coordinate of a main crack tip in the width direction |
| $X_{br}$ | mm | Coordinate of the longest branch crack tip in the width direction |
| $y_a$ | mm | Coordinate of a main crack tip in the stress loading direction |
| $y_{br}$ | mm | Coordinate of the longest branch crack tip in the stress loading direction |
| σ | N/mm$^2$ | Applied stress |
| $\sigma_{Y0}$ | N/mm$^2$ | Yield stress at room temperature |

**2.2.11.1.3** Testing equipment.

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

**2.2.11.1.3.1** Testing machines.

**2.2.11.1.3.1.1** Loading method.

Tensile load to an integrated specimen shall be hydraulically applied by testing machines.

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

**2.2.11.1.3.1.2** Loading directions.

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

**2.2.11.1.3.1.3** Distance between the loading pins.

The distance between the loading pins shall be approximately 3,4*W* or more (where *W* is the width of the test specimen). Since the distance between the loading pins sometimes has an effect on the load drop associated with crack propagation, the validity of the test results is determined by the judgment method described in 2.2.11.1.7.1.

**2.2.11.1.3.2** Impact equipment and impact methods.

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

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

**2.2.11.1.4** Test specimens.

**2.2.11.1.4.1** Test specimen shapes

The standard test specimen shape is shown in Fig. 2.2.11.1.4.1. Table 2.2.11.1.4.1 shows the ranges of test specimen thicknesses, widths and width-to-thickness ratios.

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

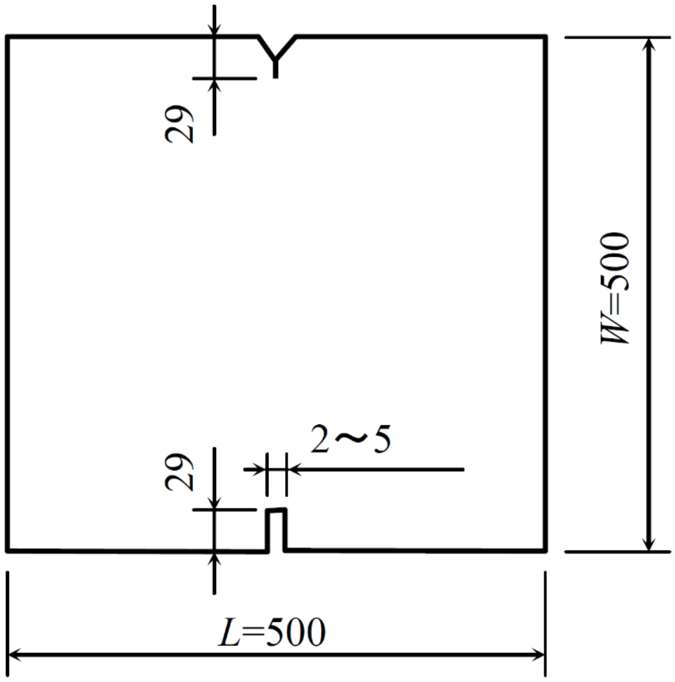



Fig. 2.2.11.1.4.1

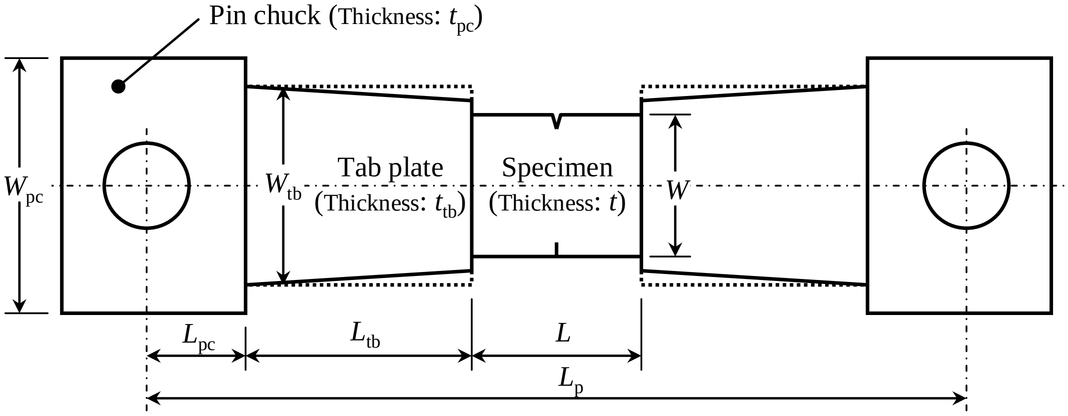
Table 2.2.11.1.4.1

**Dimensions of test specimens**

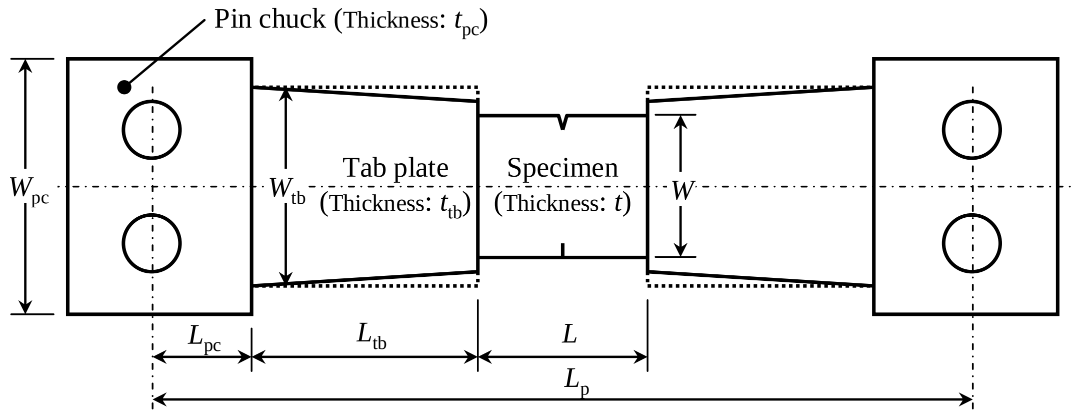
| | |
|---|---|
| Test specimen thickness, $t$ | 50 mm ≤ $t$ ≤ 100 mm |
| Test specimen width, $W$ | 350 mm ≤ $W$ ≤ 1000 mm<br>(Standard width: $W$ = 500 mm) |
| Test specimen width / test specimen thickness, $W/t$ | $W/t$ ≥ 5 |

**2.2.11.1.4.2** Shapes of tab plates and pin chucks.

The definitions of the dimensions of the tab plates and pin chucks are shown in Fig. 2.2.11.1.4.2-1. Typical examples of different structures of an integrated specimen are shown in Fig. 2.2.11.1.4.2-2.

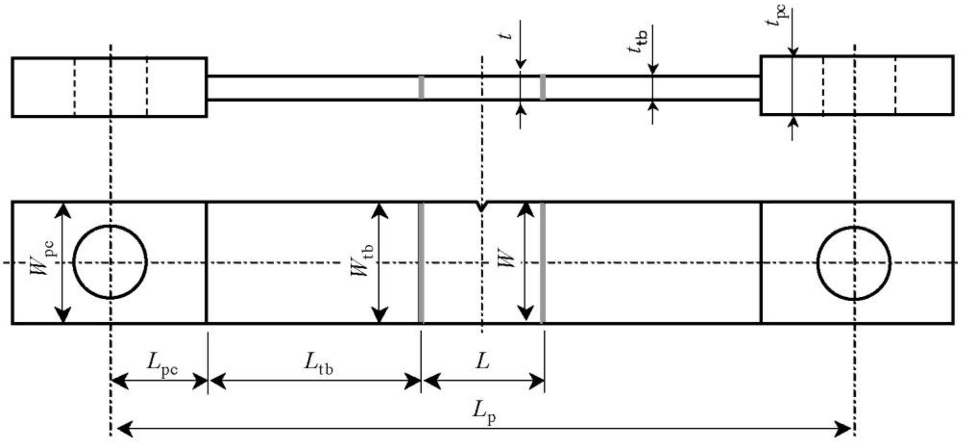



*a)*

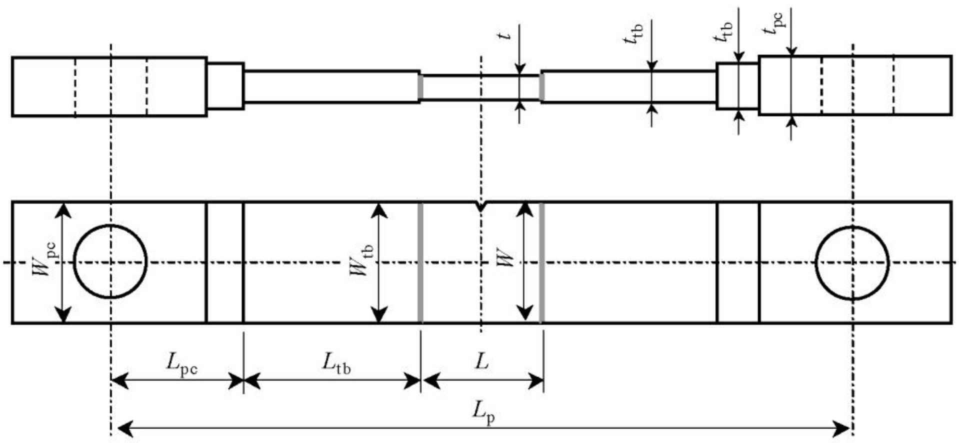



*b)*

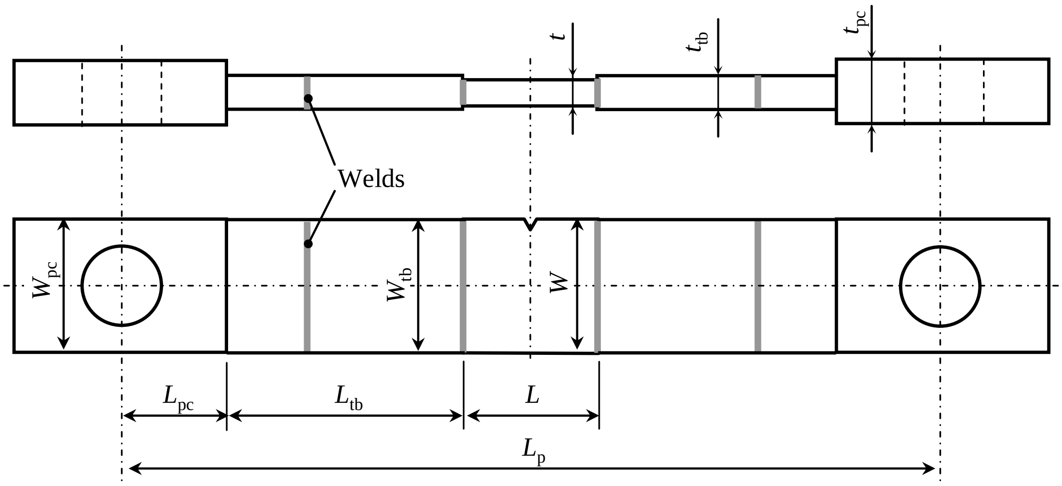
Fig. 2.2.11.1.4.2-1 Definitions of the dimensions of the tab plates and pin chucks:
*a)* — Single-pin type; b) — Double-pin type



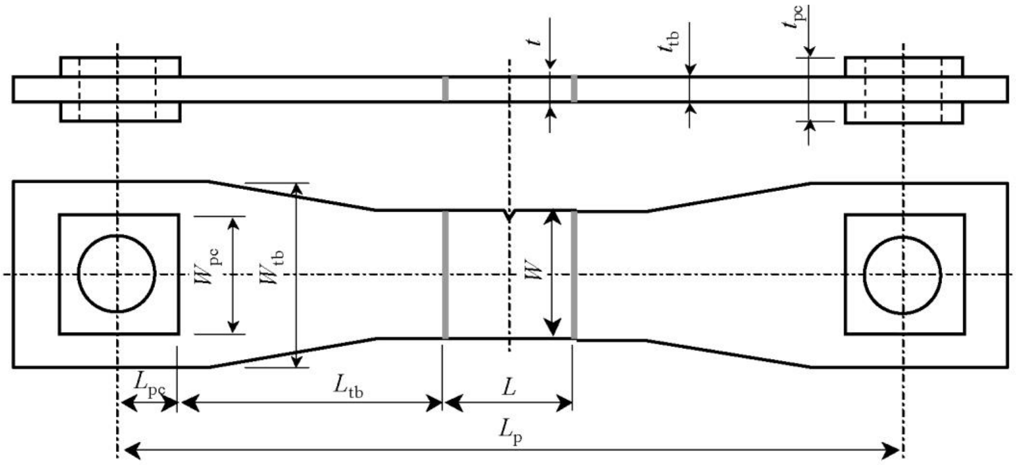

*a) example 1*



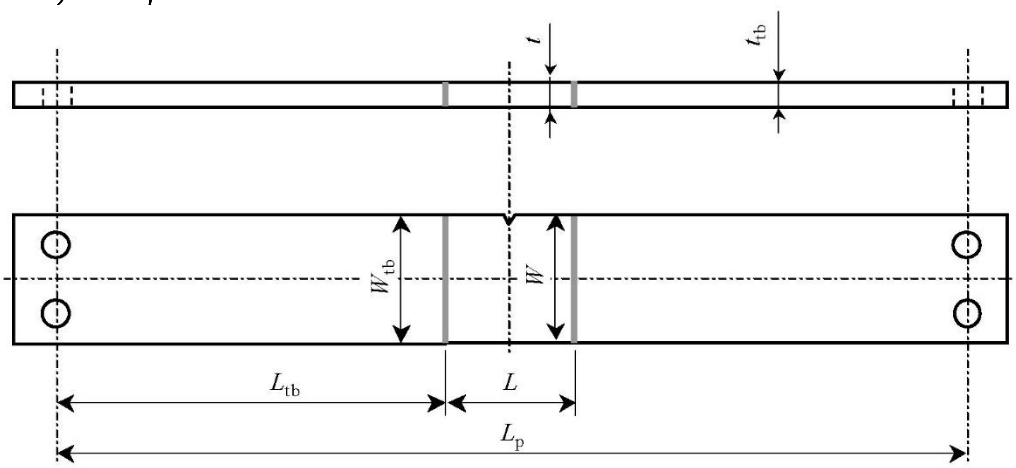

*b) example 2*




*c) example 3*




*d) example 4*




*e) example 5*

Fig. 2.2.11.1.4.2-2 Examples of shapes of tab plates and pin chucks

**2.2.11.1.4.2.1** Tab plates.

The tolerances of tab plate dimensions are shown in Table 2.2.11.1.4.2.1. When the lengths of the tab plates attached to both ends of a test specimen are different, the shorter length shall be used as the tab length, $L_{tb}$.

Table 2.2.11.1.4.2.1

**Tolerances of tab plate dimensions**

| | |
|---|---|
| Tab plate thickness, $t_{tb}$ | $0{,}8t \le t_{tb} \le 1{,}5t$ |
| Tab plate width, $W_{tb}$ | $W \le W_{tb} \le 2{,}0W$ |
| Total length of a test specimen and tab plates, $L + 2L_{tb}$<br>(Total length of a test specimen and a single tab plate $L + L_{tb}$) | $L + 2L_{tb} \ge 3{,}0W$<br>$(L + L_{tb} \ge 2{,}0W)$ |
| Tab plate length/Tab plate width | $L_{tb}/W \ge 1{,}0$ |

**2.2.11.1.4.2.2** Pin chucks.

The pin chuck width $W_{pc}$ shall be in principle equal to or more than the tab plate width $W_{tb}$.

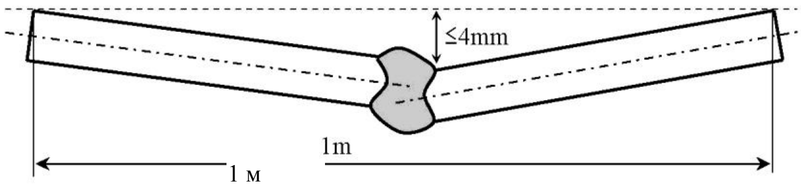
The pin chucks shall be designed to have a sufficient load bearing strength. When pin chucks attached to both ends of an integrated specimen are asymmetric, the length of the shorter one shall be used as the pin chuck length $L_{pc}$.

The distance between the pins $L_p$ is obtained from the equation $L_p = L + 2L_{tb} + 2L_{pc}$. In the case as shown in Fig. 2.2.11.4.2-2, *e*, $L_p$ is obtained by setting $L_{pc} = 0$.

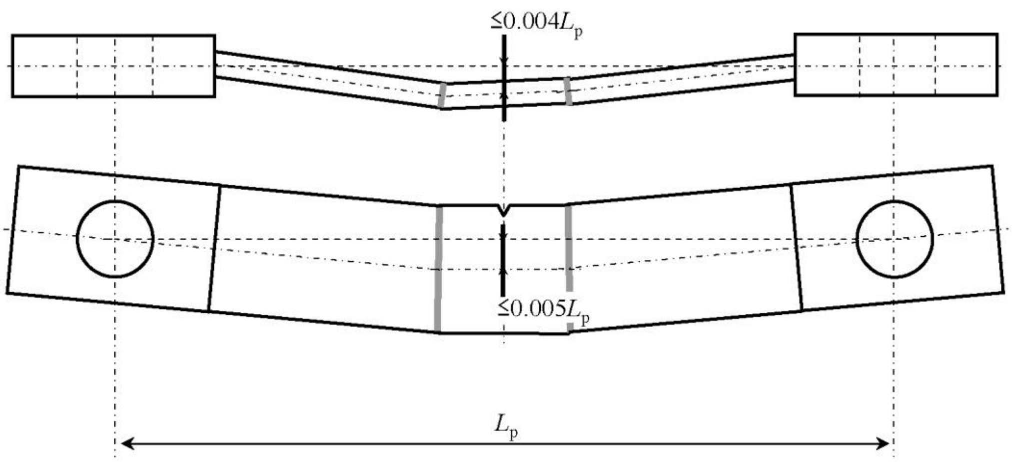
**2.2.11.1.4.3** Welding of test specimen and tab plates.

Test specimen, tab plates, and pin chucks shall be connected by welding. The welds shall have a sufficient force bearing strength to avoid their arrest toughness during testing.

The flatness, angular distortion and linear misalignment of the weld between a test specimen and a tab plate shall be prior and after preloading shall not exceed the specified values, as shown in Fig. 2.2.11.1.4.3.




*a)*




*b)*

Fig. 2.2.11.1.4.3 Accuracy (tolerances) of test specimen welds shape deviation:
(a) Flatness of weld between test specimen and tab plate

**2.2.11.1.5** Test methods for conducting the arrest toughness test, $K_{ca}$.

**2.2.11.1.5.1** Temperature control methods.

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

Temperature gradient shall be established in accordance with the following conditions:

**.1** A temperature gradient of 0,25 — 0,35 ºC/mm shall be established in a test specimen width range of 0,3*W* — 0,7*W*. When measuring the temperatures at the centre position of the test specimen thickness, it shall be kept within deviation ±2 °C for 10 min or more, whereas when measuring the temperatures on the front and back surface positions of the test specimen, it shall be kept within deviation ±2 °C for (10+0,1$t$ (mm)) minutes or more taking account of the time needed for soaking to the centre.

**.2** At the test specimen width centre 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 centre position in the length direction shall be controlled within ±5 °C. However, when temperature measurement is not performed at the centre position in the length direction, the average temperature at the closest position shall be used as the temperature at the centre position in the length direction.

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

**2.2.11.1.5.2** Crack initiation methods.

Impact energy shall be applied to a test specimen to initiate a crack. The value of impact energy shall be calculated using Formula (2.2.11.1.5.2) and Fig. 2.2.11.1.5.2

$$\frac{E_i}{t} \le \min(1{,}2\sigma - 40, 200), \qquad (2.2.11.1.5.2)$$

where min means the minimum of the two values.

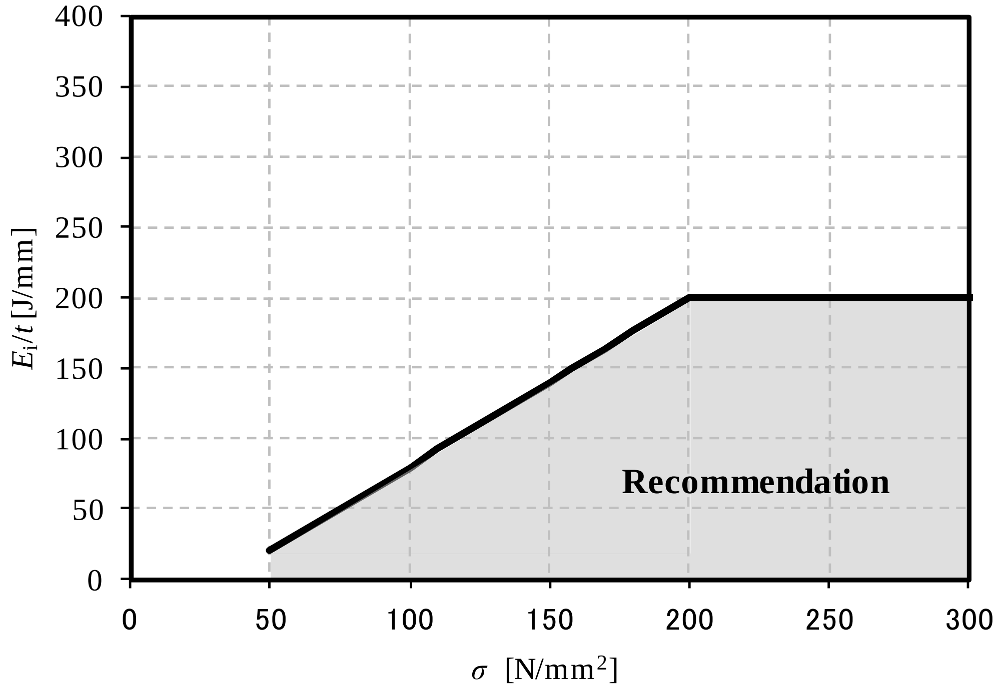



Fig. 2.2.11.1.5.2

However, if the energy is excessive, the results shall be treated as invalid data in accordance with the judgment criteria specified in 2.2.11.1.7.2.

**2.2.11.1.6** Test procedures for testing brittle crack arrest toughness.

**2.2.11.1.6.1** Pretest procedures.

**.1** install an integrated specimen in the testing machine;

**.2** mount a cooling device on the test specimen. A heating device may also be mounted in the case of stipulated heating on the test specimen;

**.3** install an impact apparatus specified in 2.2.11.1.3.2, on the testing machine. Place an appropriate reaction force receiver (anvil) as necessary.

N o t e . The above procedures 1 — 3 shall be provided by the testing laboratory;

**.4** after checking that all measured values of the thermocouples indicate room temperature, start cooling. The temperature distribution and the holding time shall be as in compliance with in 2.2.11.1.5.1;

**.5** set an impact apparatus, as specified in 2.2.11.1.3.2 so that it can supply predetermined energy to the test specimen;

**.6** apply static force to the test specimen until it reaches the predetermined value. This force shall be applied after temperature control to prevent autonomous crack initiation during force increase. The loading rate and applied stress shall satisfy the conditions described below, respectively:

**.6.1** the loading rate shall ensure maintaining the set temperatures of the specimen. At that, the rate shall be limited to prevent over-shooting of the load and premature crack initiation;

**.6.2** applied stress/yield stress ratio shall be within the range shown by equation $\sigma \leq \frac{2}{3}\sigma_{Y0}$. As a guide, a value equal to 1/6 of $\sigma_{Y0}$. or more is desirable;

**.7** to initiate a crack, the notch may be cooled further immediately before impact on the condition that the cooling does not disturb the temperature in the range of $0{,}3W$ — $0{,}7W$. The test temperature in this case shall be the measured temperature obtained from the temperature record of a testing laboratory immediately before the further notch cooling;

**.8** record the static force value measured by a force recorder.

**2.2.11.1.6.2** Loading procedures:

**.1** after holding a predetermined force for 30 s or more, apply an impact to the wedge using the impact apparatus. If a crack initiates autonomously and the exact force value at the time of the crack initiation cannot be obtained, the test is invalid;

**.2** after the impact, record the force value measured by the force recorder;

**.3** when the force after the impact is smaller than the test force, consider that crack initiation has occurred.

Note. An increase in the number of times of impact may cause a change in the shape of the notch of the test specimen. Since the number of impact has no effect on the value of brittle crack arrest toughness, no limit is specified for the number of impact. However, because the temperature gradient is often distorted by impact, the test shall be conducted again, beginning from temperature control when applying repeated impact to the wedge. In such a case, the requirements of 2.2.11.1.3.2 shall be complied with.

**.4** when crack initiation, propagation, and arrest are observed, remove the force.

**2.2.11.1.6.3** Procedures after testing:

**.1** remove the impact apparatus providing access to the specimen;

**.2** remove the cooling device, thermocouples, and strain gauges;

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

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

**2.2.11.1.6.4** Observation of fracture surfaces:

**.1** photograph the fracture surfaces and propagation path;

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

**.2.1** crack re-initiation.

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

**.2.2** crack branching.

In the case where a crack deviates from the direction vertical to the loading direction, the length projected to the plane vertical to the loading line is defined as the arrest crack length. Similarly, in the case of crack branching, the length of the longest branch crack projected to the plane vertical to the loading line is defined as the branch crack length. More specifically, from the coordinates ($x_a$, $y_a$) of the arrest crack tip position and the coordinates ($x_{br}$, $y_{br}$) of the branch crack tip position shown in Fig. 2.2.11.1.6.4.2.2, 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.

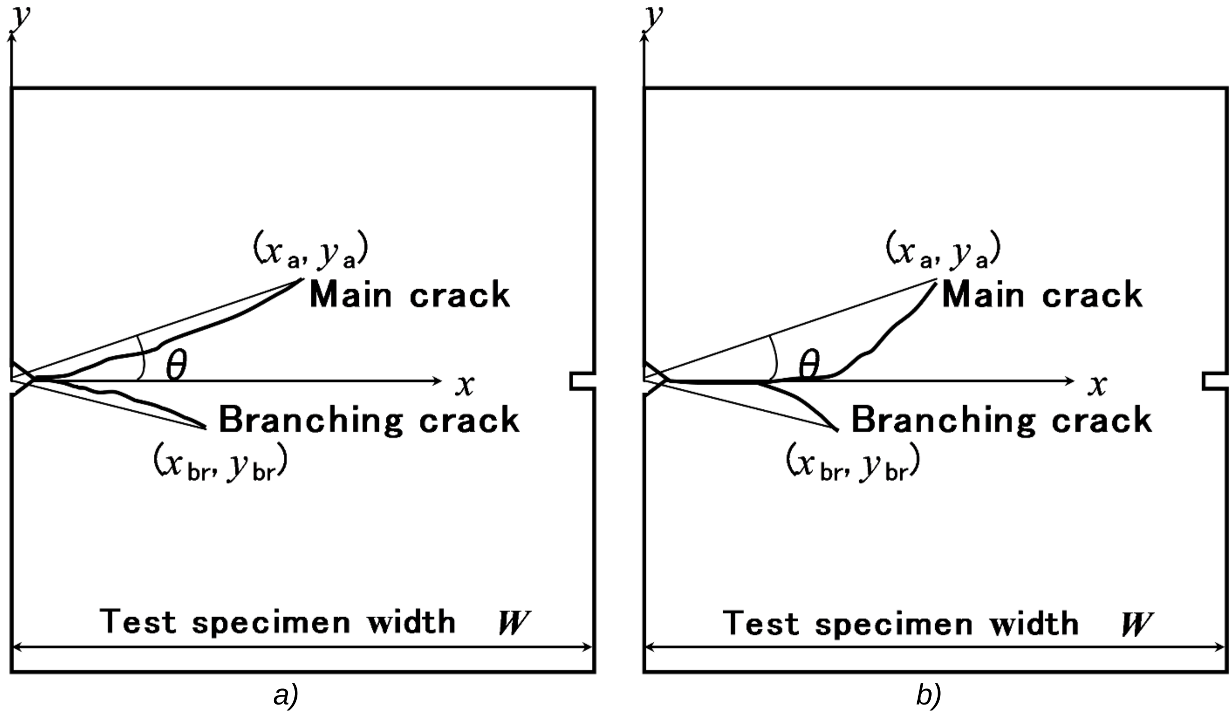



Fig. 2.2.11.1.6.4.2.2 Measurement methods of main crack and branch crack lengths:
*a* — Case of branching from notch; *b* — Case of branching during brittle crack propagation

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

**2.2.11.1.7** Determination of arrest toughness.

**2.2.11.1.7.1** Judgment of arrested crack.

When an arrested crack satisfies all of the conditions below (as shown in Fig. 2.2.11.1.7.1), the length of the arrested crack determined by 2.2.11.1.6.4 is valid. If any of the conditions is not met, the arrest toughness calculated from 2.2.11.1.7.3 is invalid.

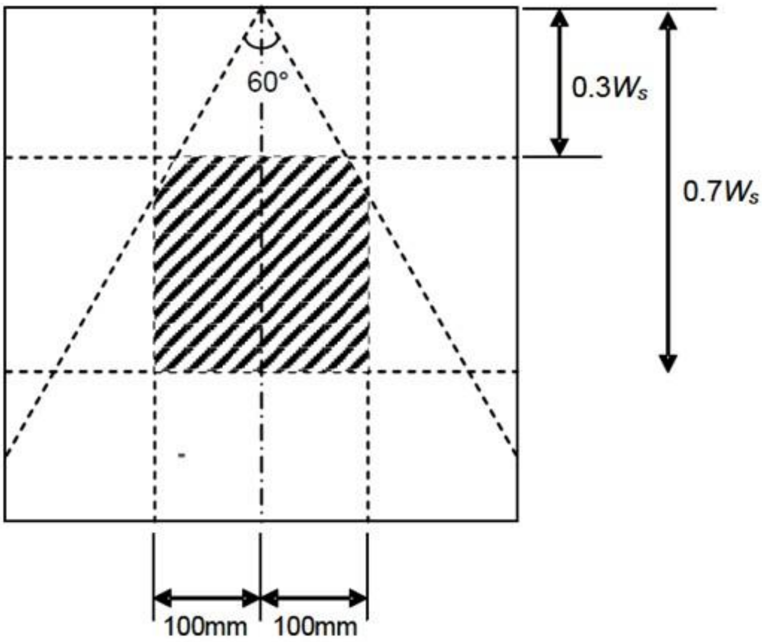



Fig. 2.2.11.1.7.1

**2.2.11.1.7.1.1** Conditions for crack propagation path:

All of the crack path from crack initiation to arrest shall be within the range shown in Fig. 2.2.11.1.7.1.1. However, in the case where a main crack tip lies within this range but a part of the main crack passes outside the range, the arrest toughness may be assessed as valid if the temperature at the most deviated position of the main crack in the *y* direction is lower than that at *y* = 0, and also *K* for the main crack falls within ± 5 % of *K* for a straight crack of the same *a*. The calculation method of $K_s$ for the main crack and a straight crack is obtained from formula:

$$K = K_I \cos^3\left(\frac{\varphi}{2}\right) + 3K_{II}\cos^2\left(\frac{\varphi}{2}\right)\sin\left(\frac{\varphi}{2}\right) \qquad (2.2.11.1.7.1.1)$$

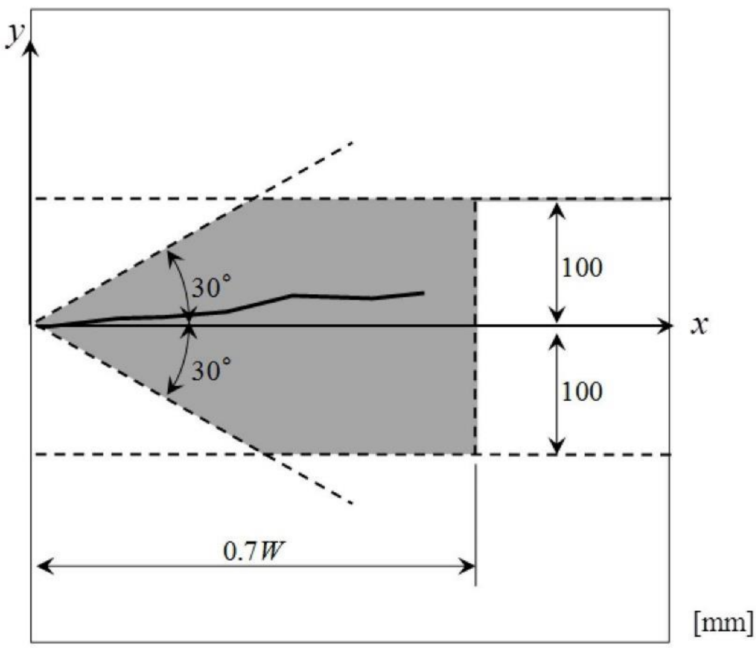



Fig. 2.2.11.1.7.1.1 Allowable range of main crack propagation path

**2.2.11.1.7.1.2** Conditions for arrest crack length.

$$0{,}3 \le \left(\frac{a}{W}\right) \le 0{,}7; \qquad (2.2.11.1.7.1.2\text{-}1)$$
$$\left(\frac{a}{t}\right) \ge 1{,}5; \qquad (2.2.11.1.7.1.2\text{-}2)$$
$$\left(\frac{a}{L_p}\right) \le 0{,}15. \qquad (2.2.11.1.7.1.2\text{-}3)$$

N o t e . Formula (2.2.11.1.7.1.2.3) ensures minimal influence of force drop at the centre of the specimen which might be caused by crack propagation and reflection of the stress wave at the two ends of the specimen. However, application of Formula (2.2.11.1.7.1.2.3) is not necessarily required if the strain and the crack length have been dynamically measured and the value of the strain at the time of arrest is 90 % or more of the static strain immediately before crack initiation.

**2.2.11.1.7.1.3** Conditions for crack straightness.

$$|y_a| \le 50 \text{ mm}. \qquad (2.2.11.1.7.1.3)$$

In the case where 50 mm < $|y_a|$ ≤ 100 mm and ≤ 30°, the result is valid only when the temperature at $x$ = 0,5$W$ and $y$ = ±100 mm falls within ± 2,5 °C of that at $x$ = 0,5$W$ and $y$ = 0.

**2.2.11.1.7.1.4** Conditions for crack branching.

$$\left(\frac{x_{br}}{x_a}\right) \le 0{,}6. \qquad (2.2.11.1.7.1.4)$$

**2.2.11.1.7.2** Assessment of impact energy.

Impact energy shall satisfy Formula (2.2.11.1.7.2). If it does not satisfy the equation, the value of arrest toughness calculated from the equations in 2.2.11.1.7.3 is invalid.

Conditions for impact energy:

$$\frac{E_i}{E_s+E_t} \le \frac{5a-1050+1{,}4W}{0{,}7W-150} \qquad (2.2.11.1.7.2\text{-}1)$$

where $0{,}3 \le \left(\frac{a}{W}\right) \le 0{,}7$;

the variables have the following units: $a$ (mm), and $W$ (mm).

$E_i$ is impact energy calculated from the formula

$$E_i = mgh; \qquad (2.2.11.1.7.2\text{-}2);$$

$E_s$ is calculated from the formula

$$E_s = \frac{10^9F^2}{2E}\frac{L}{Wt}; \qquad (2.2.11.1.7.2\text{-}3);$$

$E_t$ is calculated from the formula

$$E_t = \frac{10^9F^2}{E}\left(\frac{L_{tb}}{W_{tb}t_{tb}} + \frac{L_{pc}}{W_{pc}t_{pc}}\right). \qquad (2.2.11.1.7.2\text{-}4)$$

N o t e s : 1. If Formula (2.2.11.1.7.2.1) is not satisfied, the influence of impact energy on the stress intensity factor is too large to obtain an accurate arrest toughness

2. In the case where the tab plates are multistage as shown in Fig. 2.2.11.1.4.2-2, *b*, calculate and total the strain energy of each tab plate using equation.

3. In the case where tab plate widths are tapered (as shown in Fig. 2.2.11.1.4.2-2, *d*), calculate the strain energy based on elastostatics.

Where the variables have the following units: *E*s (J), *E*t (J), *F* (MN), *E* (N/mm2), *L* (mm), *W* (mm), and *t* (mm).

**2.2.11.1.7.3** Calculation of arrest toughness.

The arrest toughness, $K_{ca}$, at the temperature, $T$, shall be calculated from Formula (2.2.11.1.7.3-1) using the arrest crack length, $a$, and the applied stress, σ, determined in 2.2.11.1.1.7. Calculate σ from Formula (2.2.11.1.7.3-2).

$$K_{ca} = \sigma\sqrt{\pi a}\left[\frac{2W}{\pi a}\tan\left(\frac{\pi a}{2W}\right)\right]^{1/2}; \qquad (2.2.11.1.7.3\text{-}1)$$
$$\sigma = \frac{10^6F}{Wt} \qquad (2.2.11.1.7.3\text{-}2)$$

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

If the conditions specified in 2.2.11.1.7.1 and 2.2.11.1.7.2 are not satisfied, the $K_{ca}$ calculated from Formula (2.2.11.1.7.3.1) is invalid.

**2.2.11.1.8** Reporting documents.

The report shall be drawn up in accordance with the template (refer to Table 2.2.11.1.8). The following items shall be reported:

**.1** test material: Steel type and yield stress at room temperature;

**.2** testing machine: Capacity of the testing machine;

**.3** test specimen dimensions: Thickness, width, length, angular distortion, and linear misalignment;

**.4** integrated specimen dimensions: Tab plate thickness, tab plate width, integrated specimen length including the tab plates, and distance between the loading pins;

**.5** test conditions: Applied force, applied stress, temperature gradient, impact energy, and the ratio of impact energy to the strain energy stored in the integrated specimen (sum of test specimen strain energy and tab plate strain energy);

**.6** test results:

**.6.1** judgment of arrest: crack length, presence or absence of crack branching, main crack angle, presence or absence of crack re-initiation, and arrest temperature;

**.6.2** arrest toughness value;

**.7** temperature distribution at moment of impact: thermocouple position, temperature value, and temperature distribution;

**.8** test specimen photographs: crack propagation path (one side), and brittle crack fracture surface (both sides);

**.9** dynamic measurement results: history of crack propagation velocity, and strain change at pin chucks (upon agreement with the Register).

Table 2.2.11.1.8

**Report sheet for brittle crack arrest test results**

<table>
<tr><th>Item</th><th colspan="2">Details</th><th>Symbol</th><th>Conditions/ Results</th><th>Unit</th><th>Valid/ Invalid</th></tr>
<tr><td rowspan="2">1. Test material</td><td colspan="2">Steel type</td><td>—</td><td></td><td>—</td><td>—</td></tr>
<tr><td colspan="2">Yield stress at room temperature</td><td>$\sigma_{Y0}$</td><td></td><td>N/mm$^2$</td><td>—</td></tr>
<tr><td>2. Test equipment</td><td colspan="2">Testing machine capacity</td><td>—</td><td></td><td>MN</td><td>—</td></tr>
<tr><td rowspan="4">3. Test specimen dimensions</td><td colspan="2">Thickness</td><td>$t$</td><td></td><td>mm</td><td></td></tr>
<tr><td colspan="2">Width</td><td>$W$</td><td></td><td>mm</td><td></td></tr>
<tr><td colspan="2">Length</td><td>$L$</td><td></td><td>mm</td><td></td></tr>
<tr><td colspan="2">Angular distortion +linear misalignment</td><td>—</td><td></td><td>mm /m</td><td></td></tr>
<tr><td rowspan="4">4. Integrated specimen dimensions</td><td colspan="2">Tab plate thickness</td><td>$t_{tb}$</td><td></td><td>mm</td><td></td></tr>
<tr><td colspan="2">Tab plate width</td><td>$W_{tb}$</td><td></td><td>mm</td><td></td></tr>
<tr><td colspan="2">Test specimen length including a tab plate</td><td>$L + L_{tb}$</td><td></td><td>mm</td><td></td></tr>
<tr><td colspan="2">Distance between loading pins</td><td>$L_p$</td><td></td><td>mm</td><td></td></tr>
<tr><td rowspan="5">5. Test conditions</td><td colspan="2">Applied force</td><td>$F$</td><td></td><td>MN</td><td></td></tr>
<tr><td colspan="2">Applied stress</td><td>σ</td><td></td><td>N/ mm$^2$</td><td></td></tr>
<tr><td colspan="2">Temperature gradient</td><td>—</td><td></td><td>°C /mm</td><td></td></tr>
<tr><td colspan="2">Impact energy</td><td>$E_i$</td><td></td><td>J</td><td></td></tr>
<tr><td colspan="2">Ratio of impact energy to strain energy stored in integrated specimen</td><td>$E_i/(E_s+E_i)$</td><td></td><td>—</td><td></td></tr>
<tr><td rowspan="3">6. Test results</td><td rowspan="3">Judgment of crack propagation /arrest</td><td>Crack length</td><td>$a$</td><td></td><td>mm</td><td></td></tr>
<tr><td>Presence/absence of crack branching</td><td>—</td><td></td><td>—</td><td>—</td></tr>
<tr><td>Ratio of branch crack length to main crack</td><td>$X_{br}/X_a$</td><td></td><td>—</td><td></td></tr>
</table>

| Item | Details | | Symbol | Conditions/ Results | Unit | Valid/ Invalid |
|---|---|---|---|---|---|---|
| | | Main crack angle | $\theta$ | | Degree (°) | |
| | | Presence/absence of crack re-initiation | — | | — | |
| | | Temperature at crack arrest position | $T$ | | °C | |
| | Arrest toughness value | | $K_{ca}$ | | N/mm$^{3/2}$ | |
| 7. Temperature distribution at moment of impact | Temperature measurement position | | — | Attached | — | — |
| | Temperature at each temperature measurement position | | — | Attached | °C | — |
| | Temperature distribution curve | | — | Attached | — | |
| 8. Test specimen photographs | Crack propagation path | | — | Attached | — | |
| | Brittle crack fracture surface (both sides) | | — | Attached | — | |
| 9. Dynamic measurement results | History of crack propagation velocity | | — | Attached | — | |
| | Strain change at pin chucks | | — | Attached | — | |

**2.2.11.2** Method for obtaining $K_{ca}$ at a specific temperature and the evaluation.

**2.2.11.2.1** General.

The present requirements apply to the method for conducting multiple tests specified in 2.2.11.1 to obtain $K_{ca}$ value at a specific temperature $T_d$.

**2.2.11.2.2** Method.

A number of experimental data show dependency of $K_{ca}$ on arrest temperature, as expressed by Formula (2.2.11.2.2), where $T_K$ (K) (= T (°C) + 273), $c$ and $K_0$ are constants.

$$K_{ca} = K_0 exp\left(\frac{c}{T_K}\right) \qquad (2.2.11.2.2)$$

The arrest toughness at a required temperature $T_D$ (K) can be obtained by following the procedures below:

**.1** obtain at least four valid $Kca$ data to comply with the Rules.

**.2** approximating log $K_{ca}$ by a linear expression of $1/TK$, determine the coefficients log $K_0$ and $c$ for the data described above by using the least square method

$$logK_{ca} = logK_0 + c\frac{1}{T_K}; \qquad (2.2.11.2.2.2)$$

**.3** obtain the value of $(K_{ca}/K_0)\cdot\exp(c/T_K)$ for each data item. When the number of data outside the range of 0,85 through 1,15 is not exceeded, the least square method used in 2.2.11.2.2.2 is considered valid. Here is an integer obtained by rounding down the value of (number of all data divided by 6). If this condition is not met, conduct additional tests to add at least two data and apply the procedure in paragraph 2.2.11.2.2.2 to the data.

**.4** the value of $K_0$ exp($c/TD$) 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 2.2.11.2.2.3 is not met, these estimated values are treated as reference values.

**2.2.11.2.3** Evaluation.

The straight-line approximation of arrhenius plot for valid $K_{ca}$ data by interpolation method are to comply with either the following 2.2.11.2.2.1 or 2.2.11.2.2.2:

**2.2.11.2.3.1** The evaluation temperature of $K_{ca}$ (i.e. –10 °C) is located between the upper and lower limits of the arrest temperature, with the $K_{ca}$ corresponding to the evaluation temperature not lower than the required $K_{ca}$ (e.g. 6,000 N/mm$^{3/2}$ or 8,000 N/mm $^{3/2}$), as shown in Fig. 2.2.11.2.3.1.

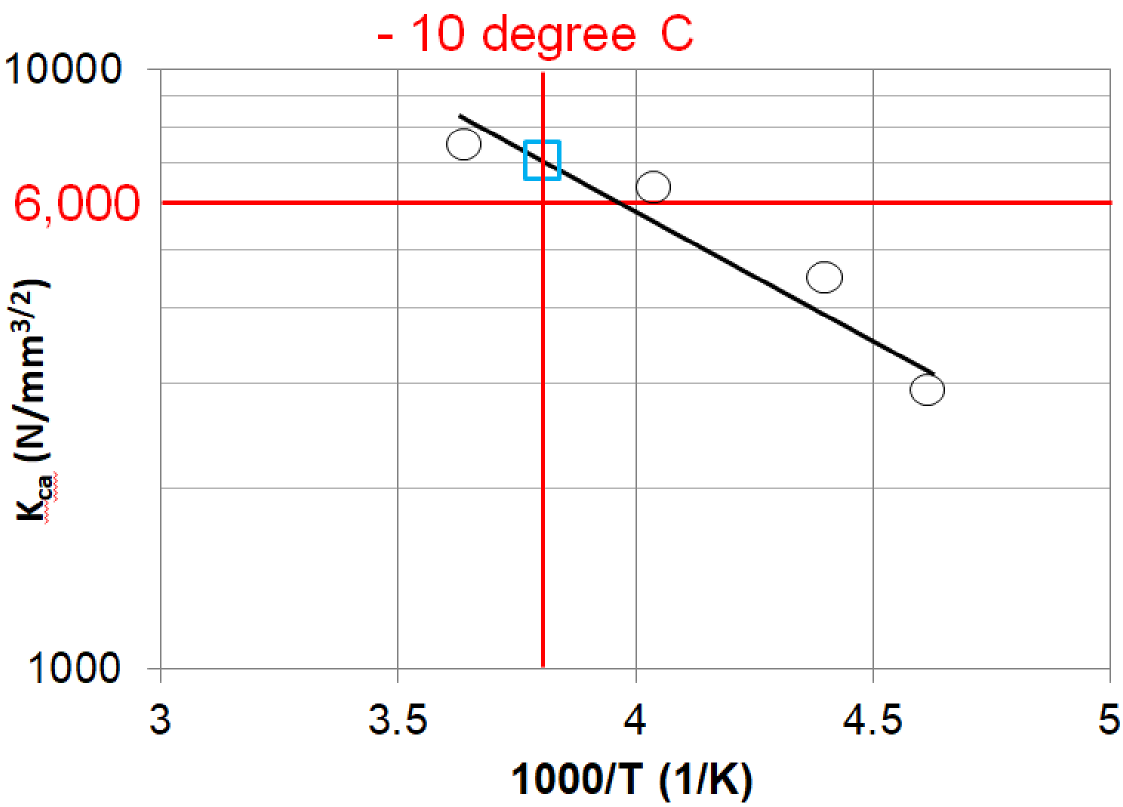



Fig. 2.2.11.2.3.1 Example for evaluation of $K_{ca}$ at –10 °C

**2.2.11.2.3.2** The temperature corresponding to the required $K_{ca}$ (e.g. 6,000 N/mm$^{3/2}$ or 8,000 N/mm$^{3/2}$) is 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. 2.2.11.2.3.2.

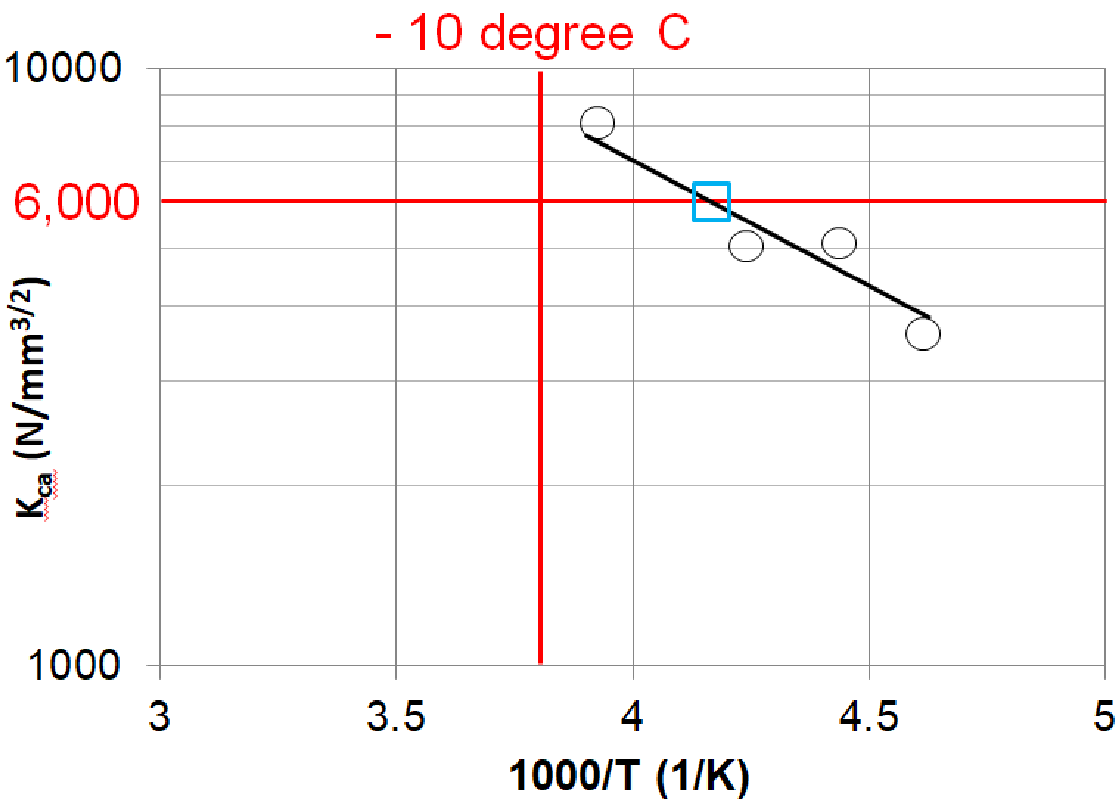



Fig. 2.2.11.2.3.2 Example for evaluation of temperature corresponding to the required $K_{ca}$

If 2.2.11.2.3 is not satisfied, conduct additional tests to satisfy this condition.

**2.2.11.3** Double tension type arrest test.

**2.2.11.3.1** Features of this test method.

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

The narrow connection part of the main plate and the secondary loading tab in this test suppress the flow of the tension stresses of the secondary loading tab into the main plate.

The values of arrest toughness obtained by this method can be considered the same as the results obtained by the brittle crack arrest toughness test specified in 2.2.11.1.

The specifications described in 2.2.11.1 shall be applied to conditions not mentioned in 2.2.11.3.

**2.2.11.3.2** Test specimen shapes.

The recommended shapes of the entire double tension type arrest test specimen and the secondary loading tab are shown in Fig. 2.2.11.3.2. Provisions of 2.2.11.1.4.2 apply to the shapes of the tab plates and pin chucks.

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

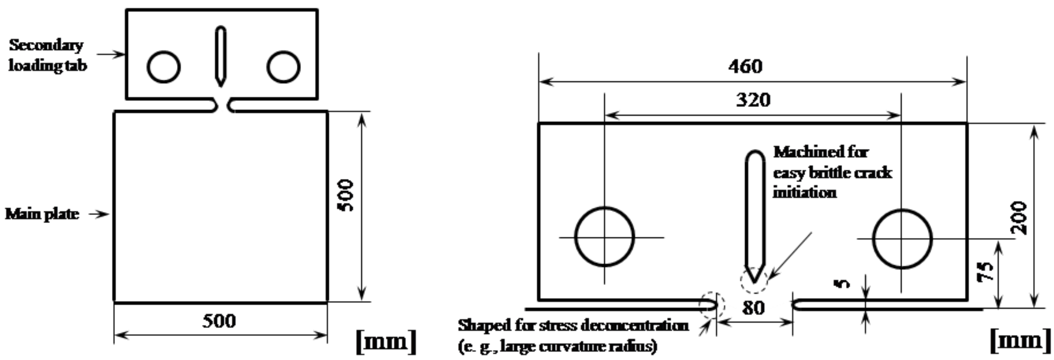



Fig. 2.2.11.3.2 Example of shape of secondary loading tab

**2.2.11.3.3** Temperature conditions and temperature control methods.

The specifications for temperature gradients and methods for establishing the temperature gradient are described in 2.2.11.1.5. In addition, in the double tension type arrest test, the secondary loading tab must be cooled. The secondary loading tab is cooled without affecting the temperature gradient of the main plate. As in the cooling method for test specimens described in 2.2.11.1, cooling may be applied using a cooling box and a coolant. The temperature of the secondary loading tab can be measured using thermocouples as described in 2.2.11.1.

**2.2.11.3.4** Secondary loading method.

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

**2.2.11.3.4.1** Holding methods of secondary loading device.

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

**2.2.11.3.4.2** Loading system.

A hydraulic type loading system is most suitable for applying a force to the secondary loading tab. Provisions of 2.2.11.1.4.2 apply to the shapes of the tab plates and pin chucks.

**2.2.11.3.4.3** Loading method.

The method of loading the secondary loading tab shall be a pin type loading method. A loading method other than a pin type may be used by agreement with the Register. The loading rate is not specified.

**2.2.11.4** Requirements for undertaking isothermal Crack Arrest Temperature (CAT) test.

**2.2.11.4.1** Scope of application.

**2.2.11.4.1.1** Provisions of 2.2.11.4 shall be applied according to the scope defined in 3.19.

**2.2.11.4.1.2** Provisions of 2.2.11.4 specify the requirements for test procedures and test conditions when using the isothermal crack arrest test to determine a valid test result under isothermal conditions and in order to establish the crack arrest temperature (*CAT*). The requirements of 2.2.11.4 are applicable to steels with thickness over 50 mm and not greater than 100 mm.

**2.2.11.4.1.3** This method uses an isothermal temperature in the test specimen being evaluated. Unless otherwise specified in 2.2.11.4, the other test parameters shall be in accordance with 2.2.11.1.

**2.2.11.4.1.4** Table 3.19.2.2.2 gives the relevant requirements for the brittle crack arrest property described by the crack arrest temperature (CAT).

**2.2.11.4.1.5** The manufacturer shall submit the test procedure to the Register for review prior to testing.

**2.2.11.4.2** Symbols and their significance.

**2.2.11.4.2.1** Requirements of Table 2.2.11.4.2.1 supplement those of Table 2.2.11.1.2 with specific symbols for the isothermal test.

Table 2.2.11.4.2.1

**Nomenclature supplementary to Table 2.2.11.1.2**

| Symbol | Unit | Significance |
|---|---|---|
| $t$ | mm | Test specimen thickness |
| $L$ | mm | Test specimen length |
| $W$ | mm | Test specimen width |
| $a_{MN}$ | mm | Machined notch length on specimen edge |
| $L_{SG}$ | mm | Side groove length on side surface from the specimen edge. $L_{SG}$ is defined as a groove length with constant depth except a curved section in depth at side groove end |
| $d_{SG}$ | mm | Side groove depth in section with constant depth |
| $L_{EB}$-min | mm | Minimum length between specimen edge and electron beam re-melting zone front |
| $L_{EB–s1, –s2}$ | mm | Length between specimen edge and electron beam re-melting zone front appeared on both specimen side surfaces |
| $L_{LTG}$ | mm | Local temperature gradient zone length for brittle crack runway |
| $a_{arrest}$ | mm | Arrested crack length |
| $T_{target}$ | °C | Target test temperature |
| $T_{test}$ | °C | Defined test temperature |
| $T_{arrest}$ | °C | Target test temperature at which valid brittle crack arrest behavior is observed |
| σ | N/mm2 | Applied test stress at cross section of $W \times t$ |
| *SMYS* | N/mm2 | Specified minimum yield strength of the tested steel grade to be approved |
| *CAT* | °C | Crack arrest temperature, the lowest temperature, $T_{arrest}$, at which running brittle crack is arrested |

**2.2.11.4.3** Testing equipment.

**2.2.11.4.3.1** The test equipment to be used shall be of the hydraulic type of sufficient capacity to provide a tensile load equivalent to 2/3 of *SMYS* of the steel grade to be approved.

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

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

**2.2.11.4.3.4** The detailed requirements for testing equipment are specified in 2.2.11.1.3.

**2.2.11.4.4** Test specimens.

**2.2.11.4.4.1** Impact type crack initiation

**2.2.11.4.4.1.1** Test specimens shall be in accordance with 2.2.11.1.4, unless otherwise specified.

**2.2.11.4.4.1.2** Specimen dimensions are shown in 2.2.11.4.4.1.2. The test specimen width, *W,* shall be 50 mm. The test specimen length, *L*, shall be equal to or greater than 500mm.

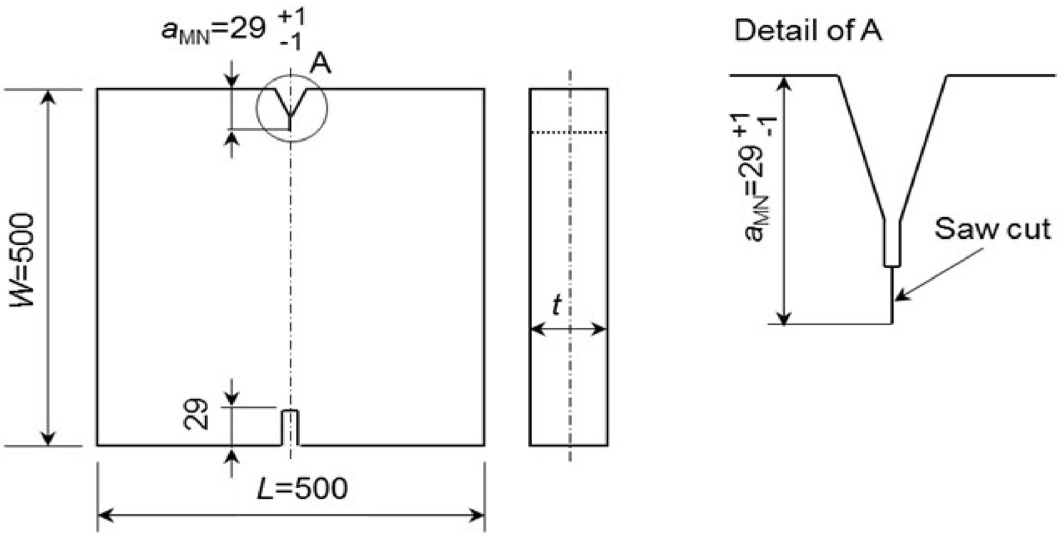



Fig. 2.2.11.4.4.1.2 Test specimen dimensions for an impact type specimen

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

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

**2.2.11.4.4.1.4** Requirements for side grooves are described in 2.2.11.4.4.4.

**2.2.11.4.4.2** Double tension type crack initiation

**2.2.11.4.4.2.1** Reference shall be made to 2.2.11.3 for the shape and sizes in secondary loading tab and secondary loading method for brittle crack initiation.

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

**2.2.11.4.4.3** Embrittled zone setting

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

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

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

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

**2.2.11.4.4.3.5** In EBW embrittlement, zone shall be of an appropriate quality.

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

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

**2.2.11.4.4.4** Side grooves.

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

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

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

**2.2.11.4.4.4.4** The length of side groove, *LSG* shall be no shorter than the sum of the required embrittled zone length of 150 mm.

**2.2.11.4.4.4.5** When side grooves would be introduced, the side groove depth, the tip radius and the open angle are not regulated, but are adequately selected in order to avoid any shear lips over 1 mm thickness in either side. An example of side groove dimensions are shown in Fig. 2.2.11.4.4.4.5.

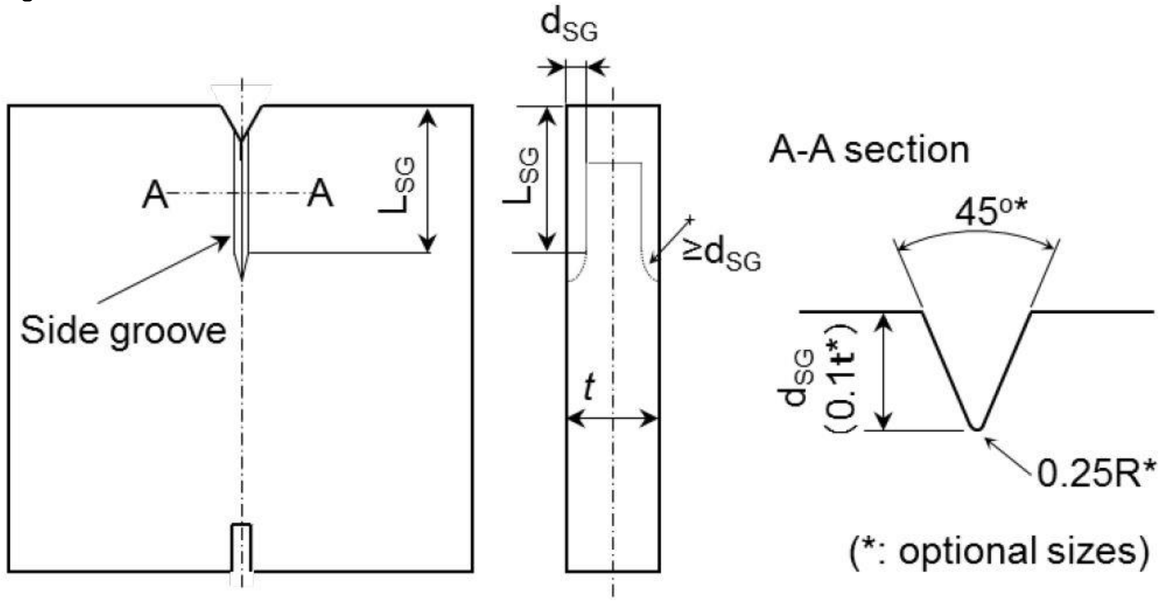



Fig. 2.2.11.4.4.4.5 Side groove configuration and dimensions

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

**2.2.11.4.4.5** Nominal length of embrittled zone.

**2.2.11.4.4.5.1** The length of embrittled zone shall be nominally equal to 150 mm in both systems of EBW and LTG.

**2.2.11.4.4.5.2** EBW zone length is regulated by three measurements on the fracture surface after test (as shown in Fig. 2.2.11.4.4.5.2), $L_{EB}$-min between specimen edge and EBW front line, EBW, $L_{EB-s1}$ and $L_{EB-s2}$.

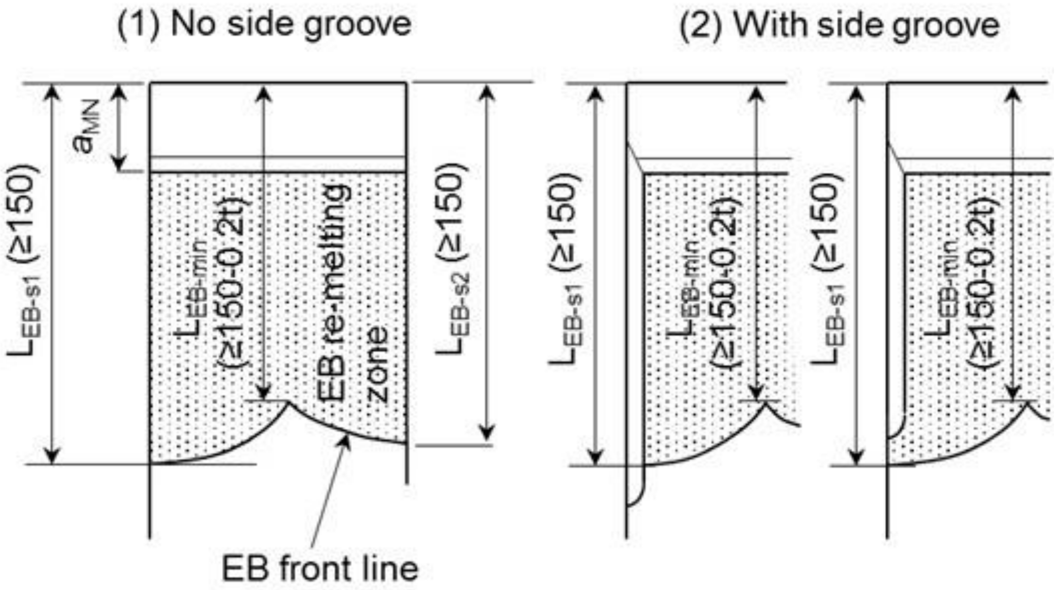



Fig. 2.2.11.4.4.5.2 Definition of EBW length

**2.2.11.4.4.5.3** The minimum length between specimen edge and EBW front line, $L_{EB}$-min should be no smaller than 150 mm. However, it may be acceptable even if $L_{EB}$-min is no smaller than 150 mm – 0,2*t*, where *t* is specimen thickness. When $L_{EB}$-min is smaller than 150 mm, a temperature safety margin shall be considered into $T_{test}$ (refer to 2.2.11.4.8.1.2).

**2.2.11.4.4.5.4** The other two are the lengths between specimen edge and EBW front appeared on both side surfaces, as denoted with $L_{EB-s1}$ and $L_{EB-s2}$. Both of $L_{EB-s1}$ *and* $L_{EB-s2}$ shall be no smaller than 150 mm.

**2.2.11.4.4.5.5** In LTG system, LLTG shall be set as 150 mm and over.

**2.2.11.4.4.6** Tab plate / pin chuck details and welding of test specimen to tab plates.

**2.2.11.4.4.6.1** The configuration and size of tab plates and pin chucks shall comply with those specified in 2.2.11.1.4.2. The welding distortion in the integrated specimen, which is welded with specimen, tab plates and pin chucks, shall be also within the requirements of 2.2.11.1.4.3.

**2.2.11.4.5** Test method.

**2.2.11.4.5.1** Preloading.

**2.2.11.4.5.1.1** Preloading at room temperature may be applied to avoid unexpected brittle crack initiation at test. The applied load value shall be no greater than the test stress. Preloading can be applied at higher temperature than ambient temperature when brittle crack initiation is expected at preloading process. The specimen shall not be subjected to temperature higher than 100 °C.

**2.2.11.4.5.2** Temperature measurement and control.

**2.2.11.4.5.2.1** Temperature control plan showing the number and position of thermocouples shall be in accordance with 2.2.11.4.5.2.

**2.2.11.4.5.2.2** Thermocouples shall be attached to both sides of the test specimen at a maximum interval of 50 mm in the whole width and in the longitudinal direction at the test specimen center position (0,5*W*) within the range of ± 100mm from the centerline in the longitudinal direction (refer to Fig. 2.2.11.4.5.2.2).

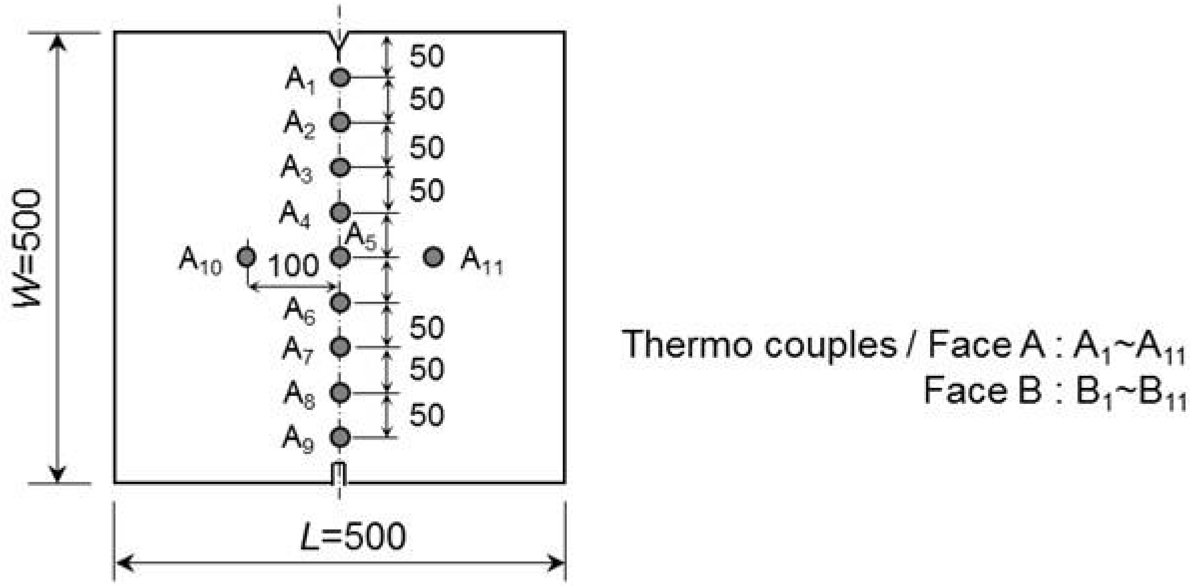



Fig. 2.2.11.4.5.2.2 Locations of temperature measurement

**2.2.11.4.5.2.3** EBW embrittlement.

**2.2.11.4.5.2.3.1** The temperatures of the thermocouples across the range of 0,3*W* ~ 0,7*W* in both width and longitudinal directions shall be controlled within ± 2 °C of the target test temperature, $T_{target}$.

**2.2.11.4.5.2.3.2** When all measured temperatures across the range of 0,3*W* ~ 0,7*W* have reached $T_{target}$, steady temperature control shall be kept at least for 10 + 0,1*t* (mm) minutes to ensure a uniform temperature distribution into mid-thickness prior to applying test load.

**2.2.11.4.5.2.3.3** The machined notch tip may be locally cooled to easily initiate brittle crack. Nevertheless, the local cooling shall not disturb the steady temperature control across the range of 0,3*W* ~ 0,7*W*.

**2.2.11.4.5.2.4** For LTG embrittlement.

**2.2.11.4.5.2.4.1** In LTG system, in addition to the temperature measurements shown in Fig. 2.2.11.4.5.2.2, the additional temperature measurement at the machine notch tip, $A_0$ and $B_0$ is required. Thermocouples positions within LTG zone are shown in Fig. 2.2.11.4.5.2.4.1.

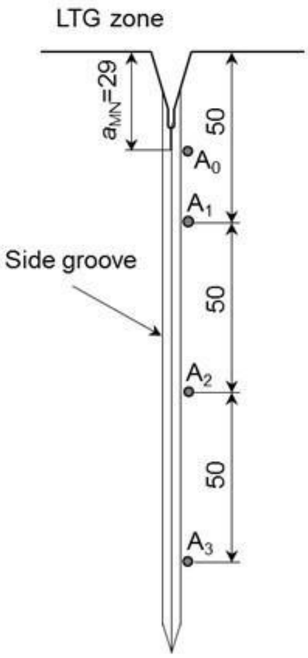



Fig. 2.2.11.4.5.2.4.1 Detail of LTG zone and additional thermocouple $A_0$

**2.2.11.4.5.2.4.2** The temperatures of the thermocouples across the range of 0,3$W$ ~ 0,7$W$ in both width and longitudinal directions shall be controlled within ± 2°C of the target test temperature, $T_{target}$. However, the temperature measurement at 0,3$W$ (location of $A_3$ and $B_3$) shall be in accordance with 2.2.11.4.5.2.4.6.

**2.2.11.4.5.2.4.3** Once the all measured temperatures across the range of 0,3W ~ 0,7W have reached $T_{target}$, steady temperature control shall be kept at least for 10 + 0,1$t$ min to ensure a uniform temperature distribution into mid-thickness, then the test load is applied.

**2.2.11.4.5.2.4.4** LTG is controlled by local cooling around the machined notch tip. LTG profile shall be recorded by the temperature measurements from $A_0$ to $A_3$ shown in Fig. 2.2.11.4.5.2.4.4.

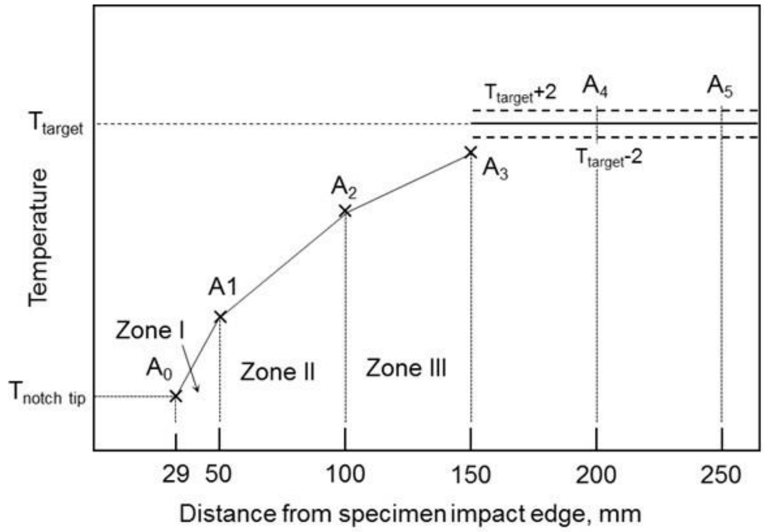



Fig. 2.2.11.4.5.2.4.4 Schematic profile of the temperature gradient in the LTG zone

**2.2.11.4.5.2.4.5** LTG zone is established by temperature gradients in three zones: Zone I, Zone II and Zone III. The acceptable range for each temperature gradient is listed in Table 2.2.11.4.5.2.4.5.

Table 2.2.11.4.5.2.4.5

**Acceptable LTG range**

| Zone | Location from edge | Acceptable range of temperature gradient |
|---|---|---|
| Zone I | 29 mm — 50 mm | 2,00 °C/mm — 2,30 °C/mm |
| Zone II | 50 mm — 100 mm | 0,25 °C/mm — 0,60 °C/mm |
| Zone III[1] | 100 mm —150 mm | 0,10 °C/mm — 0,20 °C/mm |
| [1] The Zone III arrangement is mandatory. | | |

**2.2.11.4.5.2.4.6** Two temperature measurements at $A_2$;$B_2$ and $A_3$;$B_3$ shall satisfy the following requirements:

$T$ at $A_3$, $T$ at $B_3$ < $T_{target}$ – 2 °C;

$T$ at $A_2$ < $T$ at $A_3$ – 5 °C;

$T$ at $B_2$ < $T$ at $B_3$ – 5 °C.

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

**2.2.11.4.5.2.4.8** The temperatures from $A_0$;$B_0$ to $A_3$;$B_3$ shall be decided at test planning stage. Table 2.2.11.4.5.2.4.5 gives the recommended temperature gradients in three zones: Zone I, Zone II and Zone III in LTG zone.

**2.2.11.4.5.2.4.9** The temperature profile in LTG zone mentioned above shall be ensured after holding time at least for 10 + 0,1t min to ensure a uniform temperature distribution into mid-thickness before brittle crack initiation.

**2.2.11.4.5.2.4.10** The acceptance of LTG in the test shall be decided from Table 2.2.11.4.5.2.4.5 based on the measured temperatures from $A_0$ to $A_3$.

**2.2.11.4.5.2.5** Double tension type crack initiation specimen.

**2.2.11.4.5.2.5.1** Temperature control and holding time at steady state shall be the same as specified in 2.2.11.4.5.2.3 or in 2.2.11.4.5.2.4 according to the method specified.

**2.2.11.4.5.3** Loading and brittle crack initiation

**2.2.11.4.5.3.1** Prior to testing, a target test temperature ($T_{target}$) shall be selected.

**2.2.11.4.5.3.2** Test procedures shall be in accordance with 2.2.11.1.6 except that the applied stress shall be 2/3 of SMYS of the steel grade.

**2.2.11.4.5.3.3** The test load shall be held at the test target load or higher for a minimum of 30 s prior to crack initiation.

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

**2.2.11.4.6** Measurements after test and test validation judgment.

**2.2.11.4.6.1** Brittle crack initiation and validation.

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

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

**2.2.11.4.6.2** Crack path examination and validation

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

**2.2.11.4.6.2.2** All of the crack path from embrittled zone end shall be within the range shown in Fig. 2.2.11.4.6.2.2. If not, the test shall be considered as invalid.

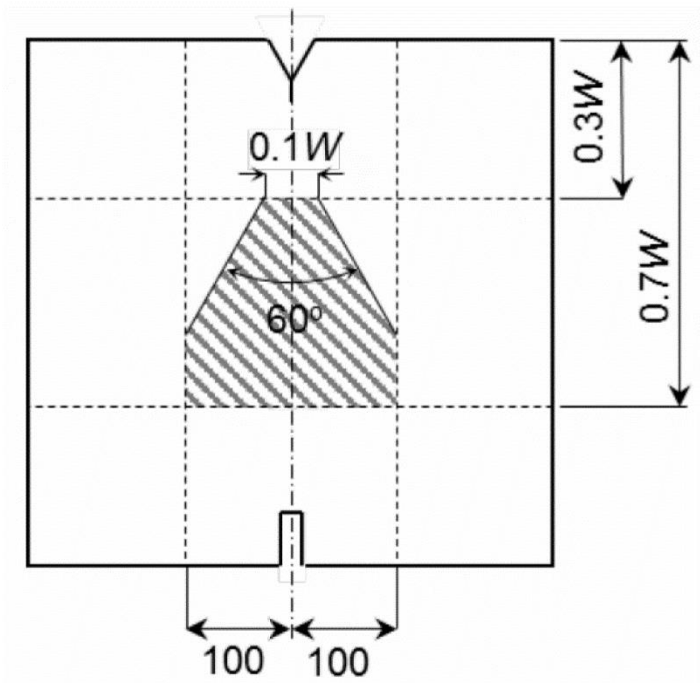



Fig. 2.2.11.4.6.2.2 Allowable range of main crack propagation path

**2.2.11.4.6.3** Fracture surface examination, crack length measurement and their validation.

**2.2.11.4.6.3.1** Fracture surface shall be observed and examined. The crack "initiation" and "propagation" shall be checked for validity and judgments recorded. The crack “arrest” positions are to be measured and recorded.

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

**2.2.11.4.6.3.3** In EBW embrittlement setting, EBW zone length is quantified by three measurements of $L_{EB\text{-}s1}$, $L_{EB\text{-}s2}$ and $L_{EB}$-min, which are defined in 2.2.11.4.4.5. When either or both of $L_{EB\text{-}s1}$, $L_{EB\text{-}s2}$ are smaller than 150 mm, the test shall be invalid. When $L_{EB}$-min is smaller than 150 mm – 0,2$t$, the test shall be invalid.

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

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

**2.2.11.4.6.3.6** The weld defects in EBW embrittled zone shall be visually examined. If detected, it shall be quantified. A projecting length of defect on the thickness line through EB weld region along brittle crack path shall be measured, and the total occupation ratio of the projected defect part to the total thickness is defined as defect line fraction (refer to Fig. 2.2.11.4.6.3.6). When the defects line fraction is larger than 10%, the test shall be invalid.

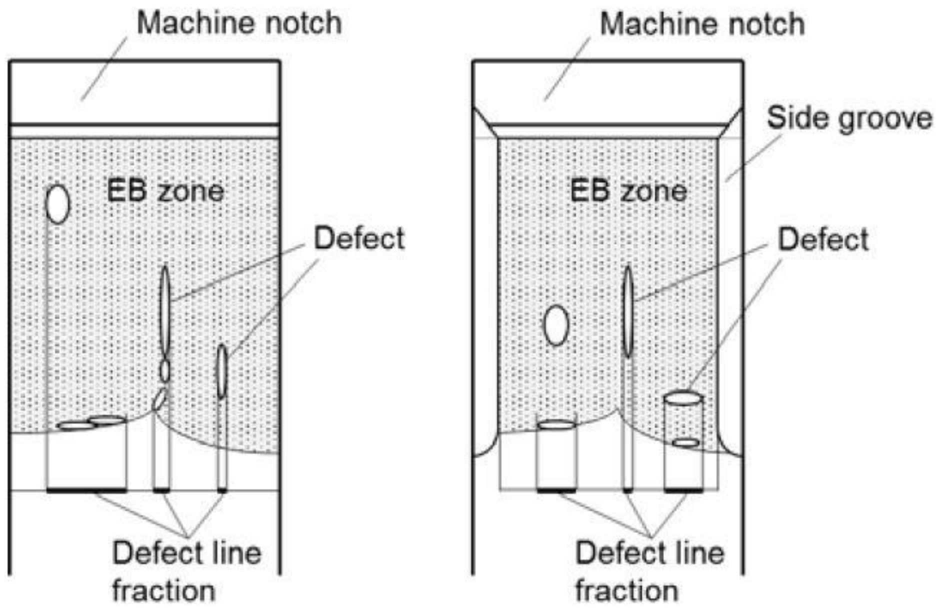



Fig. 2.2.11.4.6.3.6 Counting procedure of defect line fraction

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

**2.2.11.4.7** Judgment of "arrest" or "propagate".

**2.2.11.4.7.1** The final test judgment of "arrest", "propagate" or "invalid" is determined by the requirements of 2.2.11.4.7.

**2.2.11.4.7.2** If initiated brittle crack is arrested and the tested specimen is not broken into two pieces, the fracture surfaces should be exposed with the procedures specified in 2.2.11.1.6.3 and 2.2.11.1.6.4.

**2.2.11.4.7.3** When the specimen was not broken into two pieces during testing, the arrested crack length, $a_{arrest}$ shall 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 $a_{arrest}$.

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

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

**2.2.11.4.7.6** The test is judged as "$a_{\mathrm{arrest}}$" when the value of $a_{arrest}$ is no greater than 0,7$W$. If not, the test is judged as "propagate".

**2.2.11.4.8** $T_{test}$, $T_{arrest}$ and *CAT* determination

**2.2.11.4.8.1** $T_{test}$ determination.

**2.2.11.4.8.1.1** It shall be ensured on the thermocouple measured record that all temperature measurements across the range of 0,3*W* ~ 0,7W in both width and longitudinal direction are in the range of $T_{target}$ ±2 °C at brittle crack initiation. If not, the test shall be invalid. However, the temperature measurement at 0,3*W* (location of $A_3$ and $B_3$) in LTG system shall be exempted from this requirement.

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

**2.2.11.4.8.1.3** In LTG embrittlement, $T_{test}$ can be equated with $T_{target}$.

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

**2.2.11.4.8.2** $T_{arrest}$ determination.

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

**2.2.11.4.8.3** *CAT* determination.

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

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

**2.2.11.4.9** Reporting.

The following items shall be reported:

**.1** test material: grade and thickness;

**.2** test machine capacity;

**.3** test specimen dimensions: thickness *t*; width *W* and length *L*; notch details and length $a_{MN}$, side groove details if machined;

**.4** embrittled zone type: EBW or LTG embrittlement;

**.5** integrated specimen dimensions: Tab plate thickness, tab plate width, integrated specimen unit length including the tab plates, and distance between the loading pins, angular distortion and linear misalignment;

**.6** brittle crack trigger information: impact type or double tension. If impact type, drop weight type or air gun type, and applied impact energy;

**.7** test conditions; Applied load; preload stress, test stress;

judgments for preload stress limit, hold time requirement under steady test stress;

**.8** test temperature: complete temperature records with thermocouple positions for measured temperatures (figure and/or table) and target test temperature;

judgments for temperature scatter limit in isothermal region;

judgment for local temperature gradient requirements and holding time requirement after steady local temperature gradient before brittle crack trigger, if LTG system is used;

**.9** crack path and fracture surface: tested specimen photos showing fracture surfaces on both sides and crack path side view; Mark at "embrittled zone tip" and "arrest" positions;

judgment for crack path requirement;

judgment for cleavage trigger location (whether side groove edge or V-notch edge);

**.10** embrittled zone information.

When EBW is used: $L_{EB\text{-}s1}$, $L_{EB\text{-}s2}$ and $L_{EB}$-min:

judgment for shear lip thickness requirement;

judgment whether brittle fracture appearance area continues from the EBW front line;

judgment for EBW defects requirement;

judgment for EBW lengths, $L_{EB\text{-}s1}$, $L_{EB\text{-}s2}$ and $L_{EB}$-min requirements.

When LTG is used: LLTG.

Judgment for shear lip thickness requirement;

test results:

when the specimen did not break into two pieces after brittle crack trigger, arrested crack length $a_{arrest}$;

when the specimen broke into two pieces after brittle crack trigger,

If there is brittle crack re-initiation, arrested crack length $a_{arrest}$:

judgement for $a_{arrest}$ in the valid range (0,3*W* < $a_{arrest}$ ≤ 0,7*W*);

final judgement either "arrest", "propagate" or "invalid";

**.1** dynamic measurement results: history of crack propagation velocity, and strain change at pin chucks, if needed.

**2.2.11.4.10** Use of test for material qualification testing.

Where required, the method can also be used for determining the lowest temperature at which a steel can arrest a running brittle crack (the determined *CAT*) as the material property characteristic in accordance with 2.2.11.4.8.3."/

## 3 STEEL AND CAST IRON

2 **Глава 3.19** заменяется следующим текстом:

### "3.19 YP47 STEELS AND BRITTLE CRACK ARREST STEELS

**3.19.1 Scope.**

**3.19.1.1** General.

**3.19.1.1.1** The requirements of this Chapter apply to YP47 steels and brittle crack arrest steels as required by BCA (Brittle Crack Arrest), used in structural members of container ships in accordance with 3.1 of Part II "Hull".

**3.19.1.1.2** Unless otherwise specified in this Chapter, steel shall comply with the requirements of 3.2.

**3.19.1.2** YP47 steels.

**3.19.1.2. 1** Steels designated as YP47 refer to steels with a specified minimum yield point of 460 MPa.

**3.19.1.2.2** The YP47 steels may be applied to longitudinal structural members in the upper deck region of container ships (such as hatch side coaming, hatch coaming top and the attached longitudinals, etc.). Special consideration shall be given to the application of YP47 steels for other hull structures by the Register.

**3.19.1.2.3** This Chapter gives the requirements for YP47 steels in thickness greater than 50 mm and not greater than 100 mm intended for the upper deck region of container ships. Requirements for YP47 steels outside the scope of the said thickness range shall be agreed with the Register.

**3.19.1.3** BCA steel.

**3.19.1.3.1** The brittle crack designation may be assigned to YP36 and YP40 steels and YP47 steels specified in 3.2, which also meet the additional brittle crack arrest requirements and properties defined in this Chapter.

**3.19.1.3.2** The requirements for application of BCA steels are specified in 3.1 of Part II "Hull", and apply to longitudinal structural members in the upper deck region of container ships (such as hatch side coaming, upper deck, hatch coaming top and the attached longitudinals, etc.).

**3.19.1.3.3** The requirements of this Chapter apply to brittle crack arrest steels with thickness range of over 50 mm and not greater than 100 mm as specified in Table 3.19.2.2.4.

**3.19.2 Steel specifications.**

**3.19.2.1.1** Chemical composition of YP47 steel shall comply with the requirements of Table 3.19.2.1.1.

**3.19.2.1.2** Mechanical properties for YP47 steels shall comply with the requirements of Table 3.19.2.1.2.

**3.19.2.2** BCA steels.

**3.19.2.2.1** Brittle crack arrest steels are defined as steel plate with the specified brittle crack arrest properties measured by either the brittle crack arrest toughness $K_{ca}$ or crack arrest temperature (*CAT*).

**3.19.2.2.2** In addition to the mechanical properties for YP36 and YP40 required in 3.2 and Table 3.19.2.1.2 for YP47, brittle crack arrest steels shall comply with the requirements specified in Table 3.19.2.2.2.

**3.19.2.2.3** The brittle crack arrest properties specified in Table 3.19.2.2.2 shall be evaluated for the products during the recognition of the manufacturer. Test specimens shall be taken from each piece during certification of products as agreed by the Register.

**3.19.2.2.4** Chemical composition of brittle crack arrest steels shall comply with Table 3.19.2.2.4.

Table 3.19.2.1.1

**Chemical composition and deoxidation practice for YP47 steels without specified BCA properties**

| Grade | PCEH47 |
|---|---|
| Deoxidation Practice | Killed and fine grain treated |
| Chemical Composition, % (ladle samples)[1, 2] | |
| $C_{max}$ | 0,18 |
| Mn | 0,90 — 2,00 |
| $Si_{max}$ | 0,55 |
| $P_{max}$ | 0,020 |
| $S_{max}$ | 0,020 |
| $Al_{(acid\ soluble\ min)\ min}$ | 0,015 [3, 4] |
| Nb | 0,02 — 0,05[4, 5] |
| V | 0,05 — 0,10[4, 5] |
| $Ti_{max}$ | 0,02 5 |
| $Cu_{max}$ | 0,35 |
| $Cr_{max}$ | 0,25 |
| $Ni_{max}$ | 1,0 |
| $Mo_{max}$ | 0,08 |
| $C_{eq\ max}$ | 0,49 |
| $P_{cm\ max}$[5] | 0,22 |

[1] Where additions of any other element have been made as part of the steelmaking practice subject to approval by the Register, the content shall be indicated on Register Certificate.

[2] Variations in the specified chemical composition may be allowed subject to approval by the Register.

[3] Refer to Note 3 to Table 3.2.2-2.

.4 Refer to Note 4 to Table 3.2.2-2.

[5] The total aluminum content shall be not less than 0,12 %.

6. The carbon equivalent $C_{eq}$ value shall be calculated from the ladle analysis using the following formula:

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

[7] Cold cracking susceptibility $P_{cm}$ value shall be calculated using the following formula:

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

Table 3.19.2.1.2

**Conditions of supply, grade and mechanical properties for YP47 steels without specified BCA properties.**

| Supply condition | Grade | Tensile test | | | Impact test | | | |
|---|---|---|---|---|---|---|---|---|
| | | Yield Strength $R_{eH}$ min, MPa | Tensile Strength $R_m$, MPa | Elongation $A_5$, min, % | Test Temprature, C° | Average Impact Energy (J) min. $KV_L$ for $t$ thickness mm, min, Дж | | |
| | | | | | | $50 < t \leq 70$ | $70 < t \leq 85$ | $85 < t \leq 100$ |
| TMCP | PCEH47 | 460 | 570-720 | 17 | -40 | 53 | 64 | 75 |

Notes: 1. The additional requirements for YP47 steel with brittle crack arrest properties is specified in 3.19.2.4.
2. Other conditions of supply shall be in accordance with the Register procedures.

T a b l e 3.19.2.2.2

**Requirement of brittle crack arrest properties for brittle crack arrest steels BCA**

| Steel grade index[1] | Thickness range (mm) | Brittle crack arrest properties[2, 3] | |
|---|---|---|---|
| | | Brittle Crack Arrest Toughness $K_{ca}$ at –10 °C N/mm$^{3/2}$[4] | Crack Arrest Temperature CAT (°C)[5] |
| BCA1 | 50 < t ≤ 100 | 6000 | –10 or below |
| BCA2 | 80 < t ≤ 100[6] | 8000 | [7] |

[1] BCA1 or BCA2 index shall be affixed to the steel grade designation (e.g. PCEH40BCA1, PCEH47BCA1, PCE47BCA2).
[2] Brittle crack arrest properties for brittle crack arrest steels are to be verified by either the brittle crack arrest toughness $K_{ca}$ or crack arrest temperature (*CAT*).
[3] Where small-scale alternative tests are used for product testing (batch release testing), these test methods shall be approved by the Register.
[4] $K_{ca}$ value is to be obtained by the brittle crack arrest test specified in 2.2.11.1.
[5] *CAT* shall be obtained by the test method specified in 2.2.11.3.
[6] Steel with thicknesses of 80 mm or lower may be approved by Register.
[7] Criterion of *CAT* for brittle crack arrest steels corresponding to $K_{ca}$ = 8000 N/mm$^{3/2}$ shall be approved by the Register.

Table 3.19.2.2.4

**Chemical composition and deoxidation practice for BCA steels**

| Grade | PCE36BCA | PCE40BCA | PCE47BCA |
|---|---|---|---|
| Deoxidation Practice | Killed and fine grain treated | | |
| Chemical Composition % (ladle samples)[1, 2, 3] | | | |
| $C_{max}$ | 0,18 | | 0,18 |
| Mn | 0,90 — 2,00 | | 0,90 — 2,00 |
| $Si_{max}$ | 0,50 | | 0,55 |
| $P_{max}$ | 0,020 | | 0,020 |
| $S_{max}$ | 0,020 | | 0,020 |
| Al(растворимый в кислоте) min | 0,015[4, 5] | | 0,015[4, 5] |
| Nb | 0,02 — 0,05[5, 6] | | 0,02 — 0,05[5, 6] |
| V | 0,05 — 0,10[5, 6] | | 0,05 — 0,10[5, 6] |
| $Ti_{max}$ | 0,02[6] | | 0,02[6] |
| $Cu_{max}$ | 0,50 | | 0,50 |
| $Cr_{max}$ | 0,25 | | 0,50 |
| $Ni_{max}$ | 2,0 | | 2,0 |
| $Mo_{max}$ | 0,08 | | 0,08 |
| $C_{eq\ max}$[7] | 0,47 | 0,49 | 0,55 |
| $P_{cm\ max}$[8] | – | | 0,24 |

[1] The requirements of this Table shall replace those of Tables 3.2.2-2 and 3.19.2.1.1 respectively.
[2] Where additions of any other element have been made as part of the steelmaking practice subject to approval by the Register, the content is to be indicated on the Register Certificate.
[3] Variations in the specified chemical composition may be allowed subject to approval of the Register.
[4] Refer to Table 3.2.2-2.
[5] Refer to Table 3.2.2-2.
[6] The total niobium, vanadium and titanium content shall not exceed 0,12 %.
[7] The carbon equivalent $C_{eq}$ value shall be calculated from the ladle analysis using the following formula:

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

[8] Cold cracking susceptibility $P_{cm}$ value is to be calculated using the following formula:

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

**3.19.3 Manufacturing Approval Scheme.**

**3.19.3.1** Manufacturing Approval Scheme for YP47 Steels.

**3.19.3.1.1** Scope of application.

**3.19.3.1.1.1** The present requirements apply to the manufacturing approval scheme for YP47 steels of grade EH47.

**3.19.3.1.1.2** Unless otherwise specified in 3.19.3.1, provisions of 2.2.2, Part III "Technical Supervision for the Manufacture of Materials" of the Rules for Technical Supervision During Construction of Ships and Manufacture of Materials and Products for Ships shall be complied with.

**3.19.3.1.2** Approval tests during initial survey.

**3.19.3.1.2.1** Scope of testing.

**3.19.3.1.3.1** Regarding YP47, unless otherwise specified, the requirements shall be applicable to the scope of initial surveys equally along with the shipbuilding steels of other grades.

**3.19.3.1.2.2** Type of tests.

**3.19.3.1.2.2.1** Brittle fracture initiation test.

Deep notch test or Crack Tip Opening Displacement (*CTOD*) test may be required. Test method shallcomply with the requirements of 2.2.10.

**3.19.3.1.2.2.2** Weldability test.

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

The test method is to be in accordance with recognized national standards such as JIS Z 3158-2016 or CB/T 4364-2013. Acceptance criteria shall be tentatively in accordance with the Register’s practice.

**.2** Brittle fracture initiation test

Deep notch test or CTOD test shall be carried out. Test method and results shall comply with the requirements of 2.2.10. Test criteria shall comply with 3.5.

**3.19.3.1.2.2.3** Other tests.

In addition to the requirement specified in 3.19.3.1.2.2.1 and 3.19.3.1.2.2.2 above, the approval tests required for steels are specified in 3.13.

**3.19.3.2** Manufacturing Approval Scheme for BCA steels.

**3.19.3.2.1** Scope of application.

**3.19.3.2.1.1** The requirements of 3.19.3.2 apply to the manufacturing approval scheme for brittle crack arrest steels, as specified in 3.19.1.3.

**3.19.3.2.1.2** Unless otherwise specified in 3.19.3.2, provisions of 2.2.2 of Part III "Technical Supervision for the Manufacture of Materials" of the Rules for Technical Supervision During Construction of Ships and Manufacture of Materials and Products for Ships shall be complied with.

**3.19.3.2.2** Approval application.

**3.19.3.2.2.1** Documents to be submitted.

The manufacturer shall submit the following documents together with those required in 2.2.2.2.1. Part III "Technical Supervision for the Manufacture of Materials" of the Rules for Technical Supervision During Construction of Ships and Manufacture of Materials and Products for Ships:

**.1** in-house test reports of the brittle crack arrest properties of the steels intended for approval;

**.2** approval test program for the brittle crack arrest properties to be approved by RS.

**.3** production test procedure for the brittle crack arrest properties to be approved by RS.

**3.19.3.2.** Approval tests.

**3.19.3.2.3.1** Scope of testing.

**3.19.3.2.3.1.1** The extent of the test program is specified in 3.19.3.2.3.

If the manufacturing process and mechanism to ensure the brittle crack arrest properties for the steels intended for approval are same, provisions of 2.2.2, Part III "Technical Supervision for the Manufacture of Materials" of the Rules for Technical Supervision During Construction of Ships and Manufacture of Materials and Products for Ships shall be complied with for the extent of the approval tests.

**3.19.3.2.3.1.2** The number of test samples and test specimens may be increased when deemed necessary by the Register, based on the in-house test reports of the brittle crack arrest properties of the steels intended for approval performed under ACS supervision.

**3.19.3.2.3.2** Type of tests.

**3.19.3.2.3.2.1** Brittle crack arrest tests shall be carried out in accordance with 2.2.11 in addition to the approval tests specified in 2.2.2.3.6, Part III "Technical Supervision for the Manufacture of Materials" of the Rules for Technical Supervision During Construction of Ships and Manufacture of Materials and Products for Ships and/or 3.19.3.2.3.3.

**3.19.3.2.3.2.2** In the case of applying for addition of the specified brittle crack arrest properties index for PCEH36, PCEH40 and PCEH47 steels of which, manufacturing process has been approved by the Register, brittle crack arrest tests, chemical analyzes, tensile test and Charpy V-notch impact test shall be carried out in accordance with the provisions of this Chapter and 2.2.2 of Part III "Technical Supervision for the Manufacture of Materials" of the Rules for Technical Supervision During Construction of Ships and Manufacture of Materials and Products for Ships.

**3.19.3.2.3.3** Test specimens and testing procedure of brittle crack arrest tests.

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

**3.19.3.2.3.3.2** The loading direction of brittle crack tests shall be parallel to the final rolling direction of the test plates.

**3.19.3.2.3.3.3** The thickness of the test specimens of the brittle crack arrest tests shall be the full thickness of the test plates.

**3.19.3.2.3.3.4** The test specimens and repeat test specimens shall be taken from the same steel plate.

**3.19.3.2.3.3.5** The thickness of the test specimen shall be the maximum thickness of the steel plate requested for approval.

**3.19.3.2.3.3.6** In the case where the brittle crack arrest properties are evaluated by $K_{ca}$, the brittle crack arrest test method shall be in accordance with 2.2.11.1. In the case where the brittle crack arrest properties are evaluated by *CAT*, the test method shall be in accordance with 2.2.11.4.

**3.19.3.2.3.4** Other tests.

Additional tests may be required when deemed necessary by by the Register in addition to the tests specified above. Scope, test methods and criteria shall be greed with the Register.

**3.19.3.2.4** Results.

Provisions of 2.2.11 shall be complied with for the results. Additionally, the results of test items and the procedures shall comply with the test program approved by the Register. In the case where the brittle crack arrest properties are evaluated by $K_{ca}$ or *CAT*, the manufacturer shall also submit to the Register the brittle crack arrest test reports in accordance with 2.2.11.1 for $K_{ca}$ and 2.2.11.4 for *CAT*, accordingly.

**3.19.3.2.5** Approval and certification.

Upon satisfactory completion of the survey and tests, the Register issues the Certificate of Recognition for Manufacturer with the grade designation having the index "BCA1" or "BCA2" (e.g. PCEH40BCA1, PCE47BCA1, PCEH47BCA2)

**3.19.3.2.6** The Certificate of Recognition for Manufacturer renewal.

The manufacturer shall also submit to RS actual manufacturing records of the approved brittle crack arrest steels within the term of validity of the manufacturing approval certificate in addition to that specified in 2.1.4, Part III "Technical Supervision for the Manufacture of Materials" of the Rules for Technical Supervision During Construction of Ships and Manufacture of Materials and Products for Ships.

N o t e . Chemical composition, mechanical properties, brittle crack arrest properties (e.g. brittle crack arrest test results or small-scale alternative test results) and nominal thickness shall be described in the form of histogram or statistics.".

3 **Chapter 3.20** is deleted.

## PART XIV. WELDING

## 2 TECHNOLOGICAL REQUIREMENTS FOR WELDING

4 New paras **2.12.6** and **2.12.7** are introduced reading as follows:

"**2.12.6 Welding YH47 steel.**

**2.12.6.1** Short bead length for tack and repairs of welds by welding shall not be less than 50 mm. In the case where $P_{cm}$ is less than or equal to 0,19 $P_{cm} \leq 0,19$, 25 mm of short bead length may be adopted.

**2.12.6.2** Preheating when welding YH47 steels shall be 50 °C or over when air temperature is 5°C or below. In the case where $P_{cm} \leq 0,19$ and the air temperature is below 5°C but above 0°C, alternative preheating requirements may be adopted with RS approval.

**2.12.6.3** Special care shall be taken with the final welding so that harmful defects do not remain. Jig mountings shall be completely removed with no defects in general, otherwise the treatment of the mounting shall be approved by the Register.

**2.12.7** Welding work (such as relevant welder's qualification, short bead, preheating, selection of welding consumable, etc.) for brittle crack arrest steels shall be in accordance with the relevant requirements for each steel grade excluding index "BCA1" or "BCA2" (refer to 3.19.2.2, Part XIII "Materials").".

## 4 WELDING CONSUMABLES

5 **Para 4.7.1.1** is replaced by the following text:

"**4.7.1.1** The requirements of this Chapter supplement those in Chapters 4.3, 4.4 and 4.5 and specify the conditions for the approval and tests of the welding consumables intended for welding high strength steels meeting the requirements in 3.13 and 3.19, Part XIII "Materials".

When the special requirements are lacking, the similar requirements for approval of the welding consumables for welding normal and higher strength hull structural steels shall apply.".

6 **Para 4.7.1.3** is replaced by the following text:

"**4.7.1.3** The welding consumables for welding the high strength steels, complying with the requirements in 3.13 and 3.19, Part XIII "Materials", are divided into grades depending on the minimum yield stress of the base and deposited metals, as well as the temperature in impact testing the weld and deposited metal according to Table 4.1.2.3.

The designation of the welding consumable grade includes two groups of f basic symbols:

3, 4 and 5 for designating the temperature during testing the impact test specimens for the deposited and weld metal;

Y42, Y46, Y47, Y50, Y55, Y62 Y69, Y89 and Y96 for designating the requirements for the minimal yield stress of the deposited metal.

For the welding consumables intended for welding high strength steels, the following additional symbols according to 4.1.2.6 are used:

H10 и H5 — for content of diffusible hydrogen in the deposited metal according to 4.2.3.4;

S — for approval of welding consumables for semiautomatic welding;

M — for approval of welding consumables for multi-run welding technique;

SM — for approval of welding consumables for semiautomatic and automatic multi-run welding technique.".

7 **Table 4.7.2.4** shall be replaced by the following text:

"Table 4.7.2.4

| Grade | | Yield stress $R_e$, MPa, min. | Tensile strength $R_m$, MPa | Elongation min $A_5$ ($L_0$ = 5d), %, min. | Impact test | |
|---|---|---|---|---|---|---|
| | | | | | Test temperature (°C), °C | Impact energy, *KV*, J, min. |
| 3 | | | | | –20 | |
| 4 | Y42 | 420 | 520 — 680 | 20 | –40 | 47 |
| 5 | | | | | –60 | |
| 3 | | | | | –20 | |
| 4 | Y46 | 460 | 540 — 720 | 20 | –40 | 47 |
| 5 | | | | | –60 | |
| 3 | Y47 | 460 | 570 — 720 | 19 | –20 | 64 |

| Grade | | Yield stress $R_e$, MPa, min. | Tensile strength $R_m$, MPa | Elongation min $A_5$ ($L_0$ = 5d), %, min. | Impact test | |
|---|---|---|---|---|---|---|
| | | | | | Test temperature (°C), °C | Impact energy, *KV*, J, min. |
| 3 | Y50 | 500 | 590 — 770 | 18 | –20 | 50 |
| 4 | | | | | –40 | |
| 5 | | | | | –60 | |
| 3 | Y55 | 550 | 640 — 820 | 18 | –20 | 55 |
| 4 | | | | | –40 | |
| 5 | | | | | –60 | |
| 3 | Y62 | 620 | 700 — 890 | 18 | –20 | 62 |
| 4 | | | | | –40 | |
| 5 | | | | | –60 | |
| 3 | Y69 | 690 | 770 — 940 | 17 | –20 | 69 |
| 4 | | | | | –40 | |
| 5 | | | | | –60 | |
| 3 | Y89 | 890 | 940 — 1100 | 14 | –20 | 69 |
| 4 | | | | | –40 | |
| 3 | Y96 | 960 | 980 — 1150 | 13 | –20 | 69 |
| 4 | | | | | –40 | |

".

8 **Table 4.7.3.3** shall be replaced by the following text:

"Table 4.7.3.3

| Grade | | Tensile strength, $R_m$, MPa, min. | Impact test | | Bend test | |
|---|---|---|---|---|---|---|
| | | | Test temperature, °C | Impact energy, *KV*, J, min. | Bending angle, degrees[1)] | Ratio $D/t$[2)] |
| 3 | Y42 | 520 | –20 | 47 | 120 | 4 |
| 4 | | | –40 | | | |
| 5 | | | –60 | | | |
| 3 | Y46 | 540 | –20 | 47 | | 4 |
| 4 | | | –40 | | | |
| 5 | | | –60 | | | |
| 3 | Y47 | 570 | –20 | 64 | | 4 |
| 3 | Y50 | 590 | –20 | 50 | | 4 |
| 4 | | | –40 | | | |
| 5 | | | –60 | | | |
| 3 | Y55 | 640 | –20 | 55 | | 5 |
| 4 | | | –40 | | | |
| 5 | | | –60 | | | |
| 3 | Y62 | 700 | –20 | 62 | | 5 |
| 4 | | | –40 | | | |
| 5 | | | –60 | | | |
| 3 | Y69 | 770 | –20 | 69 | | 5 |
| 4 | | | –40 | | | |
| 5 | | | –60 | | | |
| 3 | Y89 | 940 | –20 | 69 | | 6 |
| 4 | | | –40 | | | |
| 3 | Y96 | 980 | –20 | 69 | | 7 |
| 4 | | | –40 | | | |

[1] The bend angle achieved before the origination of the first crack. Minor weld defects less than 3 mm long revealed on the specimen surface are acceptable.
[2)] D — mandrel diameter, t — specimen thickness.

".

9 **Table 4.7.4.2** shall be replaced by the following

"Table 4.7.4.2

| Grade by yield stress value | Classification symbols by diffusible hydrogen content | Maximum hydrogen content, $cm^3$ per 100 g of deposited metal |
|---|---|---|
| Y42<br>Y46<br>Y47<br>Y50 | H10 | 10 |
| Y55<br>Y62<br>Y69<br>Y89<br>Y96 | H5 | 5 |

".