S33 Requirements for Use of Extremely Thick Steel Plates

(Jan 2013)

1. Application

1.1 General

1.1.1 This UR is to be complied with for container carriers incorporating extremely thick steel plates in accordance with 1.2 and 1.3.

1.1.2 This document gives measures for identification and prevention of brittle fractures of container carriers to which extremely thick steel plates are applied for longitudinal structural members.

1.1.3 The application of the measures specified in 2, 3 and 4 is to be in accordance with Annex 1.

1.1.4 Brittle fracture toughness of welded joints is to comply with IACS UR W11, UR W28 and UR W31 (Application of YP47 steel plates) where applicable in addition to the requirements of this UR.

1.2 Steel Grade

1.2.1 This document is to be applied to container carriers to which any of YP36, YP40 and YP47 steel plates having the thickness specified in 1.3 for the longitudinal structure members.

Note: *YP36 YP40 and YP47 means the steel plates having the minimum specified yield points of 355, 390 and 460 N/mm^2, respectively.*

1.3 Thickness

1.3.1 For steel plates with thickness of over 50mm and not greater than 100mm, the measures for prevention of brittle crack initiation and propagation specified in this document are to be taken.

1.3.2 For steel plates with thickness exceeding 100mm, appropriate measures for prevention of brittle crack initiation and propagation are to be taken in accordance with each Classification Society's decision considering this document.

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Notes:

1.	This UR is to be applied by IACS Societies to ships contracted for construction on or after 1 January 2014.

2.	The "contracted for construction" date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of "contract for construction", refer to IACS Procedural Requirement (PR) No. 29.

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2.   Non-Destructive Testing (NDT) during construction (Measure No.1 of Annex 1)

Where NDT during construction is required in Annex 1, the NDT is to be in accordance with 2.1 and 2.2. Enhanced NDT as specified in 4.3.1(e) is to be carried out in accordance with the appropriate standard.

2.1   General

2.1.1 Ultrasonic testing (UT) in accordance with IACS Rec.20 or each society's requirement is to be carried out on all block-to-block butt joints of all upper flange longitudinal structural members in the cargo hold region. Upper flange longitudinal structural members include the topmost strakes of the inner hull/bulkhead, the sheer strake, main deck, coaming plate, coaming top plate, and all attached longitudinal stiffeners. These members are defined in Fig.1.
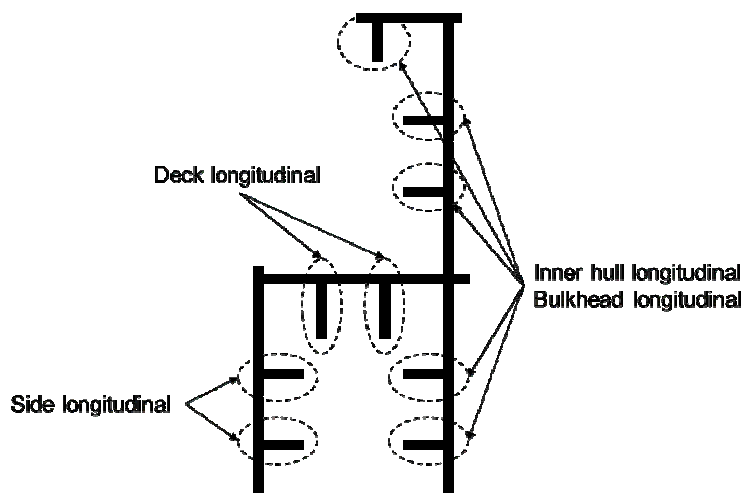
Deck longitudinal

Inner hull longitudinal
Bulkhead longitudinal

Side longitudinal

Fig.1 Upper Flange Longitudinal Structural Members

2.2   Acceptance criteria of UT

2.2.1 Acceptance criteria of UT are to be in accordance with IACS Rec.20 or each Classification Society's practice.

2.2.2 The acceptance criteria may be adjusted under consideration of the appertaining brittle crack initiation prevention procedure and where this is more severe than that found in IACS Rec.20, the UT procedure is to be amended accordingly to a more severe sensitivity.

3. Periodic NDT after delivery (Measure No.2 of Annex 1)

Where periodic NDT after delivery is required, the NDT is to be in accordance with 3.1, 3.2 and 3.3.

3.1 General

3.1.1 The procedure of the NDT is to be in accordance with IACS Rec.20 or each Society's requirements.

3.2 Timing of UT

3.2.1 Where UT is carried out, the frequency of survey is to be in accordance with individual Society requirements.

3.3 Acceptance criteria of UT

3.3.1 Where UT is carried out, acceptance criteria of UT are to be in accordance with IACS Rec.20 or each Classification Society's practice.

4. Brittle crack arrest design (Measure No.3, 4 and 5 of Annex 1)

4.1 General

4.1.1 Measures for prevention of brittle crack propagation, which is the same meaning as Brittle crack arrest design, are to be taken within the cargo hold region.

4.1.2 The approach given in this section generally applies to the block-to-block joints but it should be noted that cracks can initiate and propagate away from such joints. Therefore, appropriate measures should be considered in accordance with 4.2.1 (b) (ii).

4.1.3 Brittle crack arrest steel is defined as steel plate with measured crack arrest properties, K_{ca} at -10 degree C $\geq$ 6,000 N/mm$^{3/2}$ or other methods based on the determination of Crack Arrest Temperature (CAT).

Note 1:   The Crack Arrest Fracture Toughness K_{ca} is to be determined by the Standard ESSO Test shown in the Annex 2 or other alternative method. Crack Arrest Temperature (CAT) may also be determined by the Double Tension Wide Plate Test or equivalent. The use of small scale test parameters such as the Nil Ductility Test Temperature (NDTT) may be considered provided that mathematical relationships of NDTT to K_{ca} or CAT can be shown to be valid.

Note 2:   Where the thickness of the steel exceeds 80 mm the required K_{ca} value or alternative crack arrest parameter for the brittle crack arrest steel plate is to be specifically agreed with each Classification Society.

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4.2   Functional requirements of brittle crack arrest design

4.2.1 The purpose of the brittle crack arrest design is aimed at arresting propagation of a crack at a proper position and to prevent large scale fracture of the hull girder.

(a)   The point of a brittle crack initiation is to be considered in the block-to-block butt joints both of hatch side coaming and upper deck.

(b)   Both of the following cases are to be considered:

    (i)   where the brittle crack runs straight along the butt joint, and

    (ii)   where the brittle crack initiates or deviates away from the butt joint and runs into base metal.

4.3   Concept examples of brittle crack arrest design

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

Brittle crack arrest design for 4.2.1(b)(ii):

(a)   Brittle crack arresting steel is to be used for the upper deck along the cargo hold region in a way suitable to arrest a brittle crack initiating from the coaming and propagating into the structure below.

Brittle crack arrest design for 4.2.1(b)(i):

(b)   Where the block to block butt welds of the hatch side coaming and those of the upper deck are shifted, this shift is to be greater than or equal to 300mm. Brittle crack arrest steel is to be provided for the hatch side coaming.

(c)   Where crack arrest holes are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, the fatigue strength of the lower end of the butt weld is to be assessed. Additional countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack arrest steel in hatch side coaming.

(d)   Where Arrest Insert Plates of brittle crack arrest steel or Weld Metal Inserts with high crack arrest toughness properties are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, additional countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack arrest steel in hatch side coamings.

(e)   The application of enhanced NDT particularly time of flight diffraction (TOFD) technique using stricter defect acceptance in lieu of standard UT technique specified in 2 can be an alternative to (b), (c) and (d).

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Annex 1
Measures for Extremely Thick Steel Plates

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The thickness and the yield strength shown in the following table apply to the hatch coaming structure, and are the controlling parameters for the application of countermeasures.

If the as built thickness of the hatch coaming structure is below the values contained in the table, countermeasures are not necessary regardless of the thickness and yield strength of the upper deck.

Yield Strength (kgf/mm^2)	Thickness (mm)	Option	Measures			
			1	2	3+4	5
36	50 < t ≤ 85	-	N.A.	N.A.	N.A.	N.A.
	85 < t ≤ 100	-	X	N.A.	N.A.	N.A.
40	50 < t ≤ 85	-	X	N.A.	N.A.	N.A.
	85 < t ≤ 100	A	X	N.A.	X	X
		B	X*	N.A.**	N.A.	X
47 (FCAW)	50 < t ≤ 100	A	X	N.A.	X	X
		B	X*	N.A.**	N.A.	X
47 (EGW)	50 < t ≤ 100	-	X	N.A.	X	X

Measures:

1   NDT other than visual inspection on all target block joints (during construction) See 2 of UR S33.

2   Periodic NDT other than visual inspection on all target block joints (after delivery) See 3 of UR S33.

3   Brittle crack arrest design against straight propagation of brittle crack along weldline to be taken (during construction) See 4.3.1 (b), (c) or (d) of UR S33.

4   Brittle crack arrest design against deviation of brittle crack from weldline (during construction) See 4.3.1 (a) of UR S33.

5   Brittle crack arrest design against propagation of cracks from other weld areas such as fillets and attachment welds. (during construction) See 4.3.1 (a) of UR S33.

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Symbols:

(a) "X" means "To be applied".

(b) "N.A." means "Need not to be applied".

(c) Selectable from option "A" and "B".

Note:

*: See 4.3 (e) of UR S33.

**: may be required at the discretion of each Society.

Annex 2
Standard ESSO Test

1   Scope

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

2   Symbols

Table 1 Symbols used and their meanings

| Symbol	Unit	Meaning
t_S	mm	Thickness of test specimen
W_S	mm	Width of test specimen
L_S	mm	Length of test specimen
t_r	mm	Thickness of tab plate
W_r	mm	Width of tab plate
L_r	mm	Length of tab plate
L_P	mm	Distance between pins
a	mm	Length of crack projected on surface normal to the line of load
a_a	mm	Maximum crack length at brittle crack arrest position
T	^{o}C	Temperature of test specimen
dT/da	^{o}C/mm	Temperature gradient of test specimen
σ	N/mm^2	Gross stress in tested part ($load / W_S.t_S$)
K_{ca}	N/mm$^{3/2}$	Brittle crack arrest toughness value
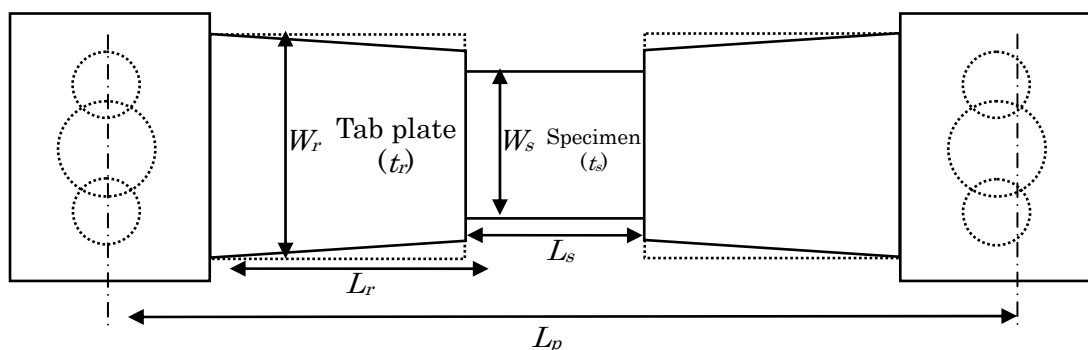
Fig.1 Conceptual view of test specimen, tab and load jig

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3   Purpose

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

4   Standard test specimen

4.1   Fig.2 shows the shape and size of the standard test specimen.
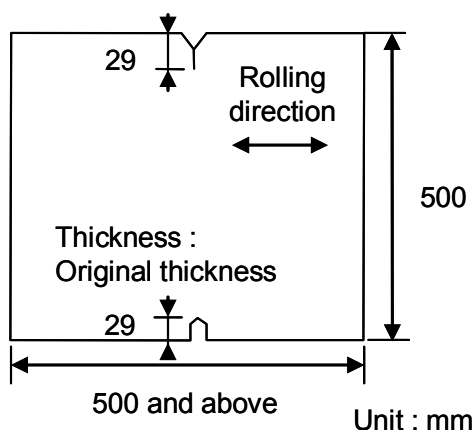

Fig.2 Shape and size of specimen

4.2   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	100 mm and below
Width of test specimen, W_s	500 mm

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

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

4.4   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.

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

5   Test equipment

5.1   The test equipment to be used is to consist of pin load type hydraulic test equipment capable of tensile tests.

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

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

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

6   Test preparations

6.1   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_r	Width: W_r
Dimensions of tab plate	$0.8t_s^{(Notes\ 1\ and\ 2)} \le t_r \le 1.5t_s$	$W_s \le W_r \le 2W_s$

Note 1: t_s : Thickness of test specimen

Note 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 $0.8t_s$.

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

6.3   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 centre of width of the test specimen.

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

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

6.6   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.

7   Test method

7.1   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.

7.2   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.

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

7.4   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.

7.5   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.

7.6   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.

7.7   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.

8   Test results

8.1   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.

8.2   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.

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

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

9   Report

9.1   The following items are to be reported:

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

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

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

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

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

(vi)   Dynamic measurement results (if measurement is carried out); crack growth rate, strain

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(vii)   Test specimen photos; fracture route, fractured surface

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

(i)   The brittle crack arrest position is to be in the range of the hatched part shown in Fig.3. In this case, if the brittle crack arrest position is more than 50 mm away from the centre 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°C of the thermocouple at the centre.

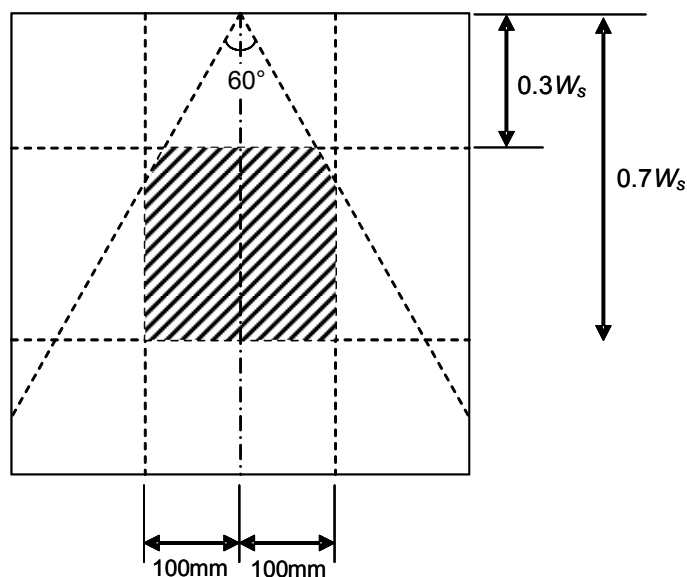(ii)   The brittle crack should not have a distinct crack bifurcation while it propagates.

Fig.3 Necessary conditions of arrest crack position

9.3   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.

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