

W24 Cast Copper Alloy Propellers

(1996)

(Rev.1

1997)

(Rev.2

May

2004)

(Rev.3

May

2012)

(Corr.1

Jan

2013)

1. Scope

These unified requirements are applicable to the moulding, casting, inspection and repair procedures of new cast copper alloy propellers, blades and bosses. Upon special consideration of the individual Classification Society these requirements may also be applied for the repair and inspection of propellers becoming damaged during service.

Note:

These requirements supersede the IACS unified requirements nos. K1 and K2 as well as the IACS Recommendation no. 4.

2. Foundry approval

2.1 Approval

All propellers and propeller components are to be cast by foundries approved by the classification society. For this purpose, the foundries have to demonstrate that they have available the necessary facilities and skilled personnel to enable proper manufacture of propellers which will satisfy these rules.

2.2 Application for approval

The approval is to be applied for at the classification society. The applications are to be accompanied by specifications of the propeller materials, manufacturing procedures, repair, NDT inspection procedures and a description of the foundry facilities, including the maximum capacity of the ladles.

2.3 Scope of the approval test

The scope of the approval test is to be agreed with the Classification Society. This should include the presentation of cast test coupons of the propeller materials in question for approval testing in order to verify that the chemical composition and the mechanical properties of these materials comply with these rules.

2.4 Inspection facilities

The foundry is to have an adequately equipped laboratory, manned by experienced personnel, for the testing of moulding materials chemical analyses, mechanical testing and microstructural testing of metallic materials. Provision is also to be made for NDT inspection. If these test facilities are not available at the foundry, details are to be provided of an approved local laboratory which will provide such services.

Notes:

1. Rev.3 of this UR is applicable to the moulding, casting, inspection and repair procedures of cast copper alloy propellers, blades and bosses from 1 July 2013.

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(cont)**3. Moulding and casting**

3.1 Pouring

The pouring must be carried out into dried moulds using degassed liquid metal. The pouring is to be controlled as to avoid turbulences of flow. Special devices and/or procedures must prevent slag flowing into the mould.

3.2 Stress relieving

Subsequent stress relieving heat treatment may be performed to reduce the residual stresses. For this purpose, the manufacturer shall submit a specification containing the details of the heat treatment to the society for approval. For stress relieving temperatures and holding times see tables 4 and 5.

4. General characteristics of castings

4.1 Freedom from defects

All castings must have a workman like finish and must be free from defects liable to impair their use. Minor casting defects which may still be visible after machining such as small sand and slag inclusions, small cold shuts and scabs shall be trimmed off by the manufacturer, cf. para 14.

4.2 Removal of defects

Casting defects which may impair the serviceability of the castings, e.g. major non-metallic inclusions, shrinkage cavities, blow holes and cracks, are not permitted. They may be removed by one of the methods described in para 14 and repaired within the limits and restrictions for the severity zones. Full description and documentation must be available for the surveyor.

5. Dimensions, dimensional and geometrical tolerances

5.1 The dimensions and the dimensional and geometrical tolerances are governed by the data contained in the approval drawings or order documents. These shall be submitted to the Surveyor at the time of the test.

The accuracy and verification of the dimensions are the responsibility of the manufacturer, unless otherwise agreed.

5.2 Statik balancing is to be carried out on all propellers in accordance with the approved drawing. Dynamik balancing is necessary for propellers running above 500 rpm.

6. Chemical composition and structure characteristics

6.1 Chemical composition

Typical copper propeller alloys are grouped into the four types CU 1, CU 2, CU 3 and CU 4 depending on their chemical composition as given in table 1. Copper alloys whose chemical composition deviate from the typical values of Table 1 must be specially approved by the Society.

Table 1 Typical chemical compositions of cast copper alloys for propellers

Alloy type	Chemical Composition (%)							
	Cu	Al	Mn	Zn	Fe	Ni	Sn	Pb
CU1	52-62	0,5-3,0	0,5-4,0	35-40	0,5-2,5	max 1,0	max 1,5	max 0,5
CU2	50-57	0,5-2,0	1,0-4,0	33-38	0,5-2,5	3,0-8,0	max 1,5	max 0,5
CU3	77-82	7,0-11,0	0,5-4,0	max 1,0	2,0-6,0	3,0-6,0	max 0,1	max 0,03
CU4	70-80	6,5-9,0	8,0-20,0	max 6,0	2,0-5,0	1,5-3,0	max 1,0	max 0,05

6.2 Metallurgical characteristics

Note:

"The main constituents of the microstructure in the copper-based alloys categories CU 1 and CU 2 are alpha and beta phase.

Important properties such as ductility and resistance to corrosion fatigue are strongly influenced by the relative proportion of beta phase (too high a percentage of beta phase having a negative effect on these properties). To ensure adequate cold ductility and corrosion fatigue resistance, the proportion of beta phase is to be kept low. The concept of the zinc equivalent should be used as control since it summarizes the effect of the tendency of various chemical elements to produce beta phase in the structure."

The structure of CU 1 and CU 2 type alloys must contain an alpha phase component of at least 25 % as measured on a test bar by the manufacturer. To ensure adequate ductility and corrosion fatigue resistance, the proportion of beta phase is to be kept low. For this purpose, the zinc equivalent defined by the following formula shall not exceed a value of 45 %:

$$\text{Zinc equivalent (\%)} = 100 - \frac{100 \cdot \% \text{ Cu}}{100 + A}$$

In which A is the algebraic sum of the following values:

- 1 . % Sn
- 5 . % Al
- 0,5 . % Mn
- 0,1 . % Fe
- 2,3 . % Ni

Note:

The negative sign in front of the elements Mn, Fe and Ni signifies that these elements tend to reduce the proportion of beta phase.

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7. Mechanical characteristics

7.1 Standardized alloys

The mechanical characteristics must conform to the values shown in table 2. These values are applicable to test specimens taken from separately cast samples in accordance with Fig. 1, or with any other recognized national standard.

Note:

These properties are a measure of the mechanical quality of the metal in each heat; and they are generally not representative of the mechanical properties of the propeller casting itself, which may be up to 30 % lower than that of a separately cast test coupon.

For integrally cast test specimens the requirements are specially to be agreed with the Society.

**Table 2 Mechanical characteristics of cast copper alloys for propellers
(separately cast test coupons)**

Alloy type	Proof stress $R_{p\ 0,2}$ [N/mm ²] min.	Tensile strength R_m [N/mm ²] min.	Elongation A_5 [%] min.
CU1	175	440	20
CU2	175	440	20
CU3	245	590	16
CU4	275	630	18

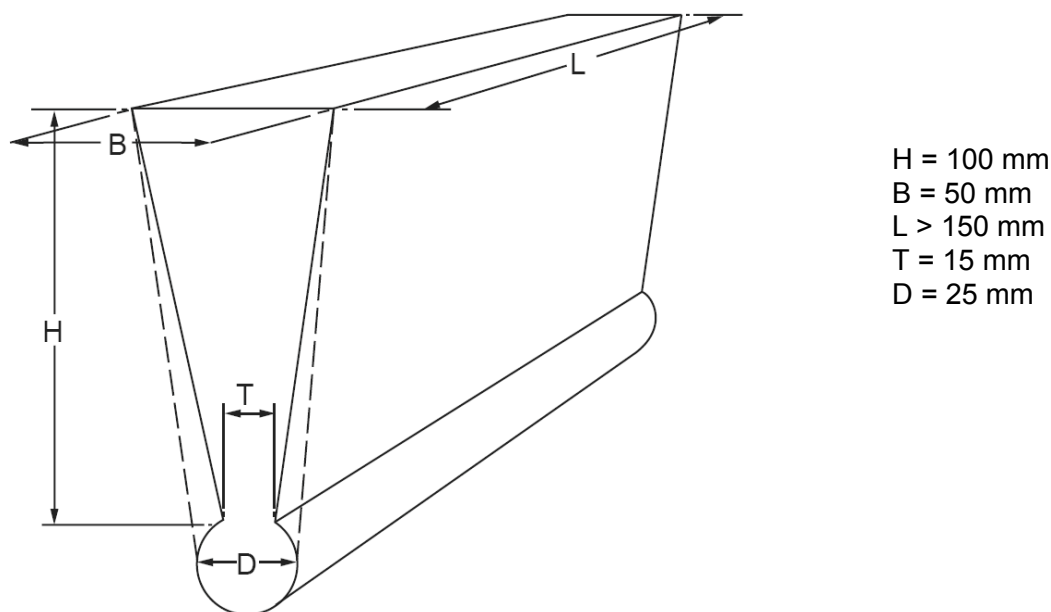


Fig.1 Test sample casting

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7.2 Other alloys

The mechanical characteristics of alloys not meeting the limiting values of Table 2 must be in accordance with a specification approved by the Society.

8 Inspection and tests

The following tests and inspections are to be performed. For test specimen's dimensions and testing procedures reference is made to UR-W2.

8.1 Chemical composition

The manufacturer shall furnish proof of the composition of each ladle.

8.2 Tensile test

8.2.1 The tensile strength, 0,2 % proof stress and elongation shall be determined by tensile test. For this purpose, at least one tensile test specimen shall be taken from each ladle.

8.2.2 Generally, the specimens shall be taken from separately cast sample pieces, see 7.1. The test samples shall be cast in moulds made of the same material as the mould for the propeller and they must be cooled down under the same conditions as the propeller.

8.2.3 If propellers are subjected to a heat treatment the test samples are to be heat treated together with them.

8.2.4 Where test specimens are to be taken from integrally cast test samples, this shall be the subject of special agreement with the Society. Wherever possible, the test samples shall be located on the blades in an area lying between 0,5 to 0,6 R, where R is the radius of the propeller. The test sample material must be removed from the casting by non thermal procedures.

8.3 Micrographic examination

The micro structure of alloy types CU 1 and CU 2 shall be verified by determining the proportion of alpha phase. For this purpose, at least one specimen shall be taken from each heat. The proportion of alpha phase shall be determined as the average value of 5 counts. The requirements of para 6.2 are to be fulfilled.

8.4 Surface quality and dimensions

8.4.1 Propeller castings should be visually inspected at all stages of manufacture and the whole surface is to be subjected to a comprehensive visual inspection in the finished condition by the Surveyor. This has to include the bore.

8.4.2 The dimensions are to be checked by the manufacturer and the report on the dimensional inspection is to be handed over to the Surveyor, who may require checks to be made in his presence.

8.4.3 The Surveyor may be require areas to be etched (e.g. by iron chloride) for the purpose of investigating weld repairs.

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(cont)**9. Non-destructive inspections**

9.1 Dye penetrant inspection

9.1.1 The severity zones "A" (see para 12) are to be subjected to a dye penetrant inspection in the presence of the Surveyor. For the inspection and acceptance standard see para 13. In zones "B" and "C" the dye penetrant inspection is to be performed by the manufacturer and may be witnessed by the Surveyor upon his request.

9.1.2 If repairs have been made either by grinding or by welding the repaired areas are additionally to be subjected to the dye penetrant inspection independent of their location and/or severity zone.

9.2 Radiographic and ultrasonic inspection

Where serious doubts exist that the castings are not free from internal defects further non-destructive inspections are to be carried out upon request of the Surveyor, e.g. radiographic and/or ultrasonic tests. For this purpose, the following is to be observed: The acceptance criteria are to be agreed between the manufacturer and the classification Society in accordance with a recognized standard.

Footnote for Guidance

The absorption of the X-rays and gamma-rays is stronger in copper-based alloys than in steel. For propeller bronzes, 300 kV X-rays can normally be used up to 50 mm and Co60 gamma-rays up to 160 mm thickness. Due to the limited thicknesses that can be radiographed as well as for other practical reasons radiography is generally not a realistic method for checking of the thickest parts of large propellers.

As a general rule, ultrasonic testing of CU 1 and CU 2 is not feasible due to the high damping capacity of these materials. For CU 3 and CU 4, ultrasonic inspection of subsurface defects is possible.

9.3 Documentation of defects and inspections

All defects requiring welding repair on the castings are to be documented preferably on drawings or special sketches showing their dimensions and locations. Furthermore, the inspection procedure is to be reported. The documentation is to be presented to the Surveyor prior to any repair weldings will be carried out.

10. Identification and marking

10.1 Identifications

The manufacturer must employ a monitoring system which enables all castings to be traced back to their heats. On request, the Surveyor shall be given proof of this.

10.2 Marking

Prior to final inspection by the Surveyor each casting shall be marked by the manufacturer at least with the following symbols:

- a) Grade of cast material or corresponding abbreviated designation
- b) Manufacturer's mark

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- c) Heat number, casting number or another mark enabling the manufacturing process to be traced back
- d) Specimen number
- e) Date of final inspection
- f) Number of the Society's test certificate
- g) Ice class symbol, where applicable
- h) Skew angle for high skew propellers.

11. Manufacturer's certificates

For each propeller the manufacturer must supply to the Surveyor a certificate containing the following details:

- a) Purchaser and order number
- b) Shipbuilding project number, if known
- c) Description of the casting with drawing number
- d) Diameter, number of blades, pitch, direction of turning
- e) Grade of alloy and chemical composition of each heat
- f) Heat or casting number
- g) Final weight
- h) Results of non-destructive tests and details of test procedure where applicable
- i) Portion of alpha-structure for CU 1 and CU 2 alloys
- k) Results of the mechanical tests
- l) Casting identification No.
- m) Skew angle for high skew propellers, see 12.1

12. Definition of skew, severity zones**12.1 Definition of skew**

The skew of a propeller is defined as follows:

The maximum skew angle of a propeller blade is defined as the angle, in projected view of the blade, between a line drawn through the blade tip and the shaft centreline and a second line through the shaft centreline which acts as a tangent to the locus of the mid-points of the helical blade section, see Fig 2.

High skew propellers have a skew angle greater than 25°, low skew propellers a skew angle of up to 25°.

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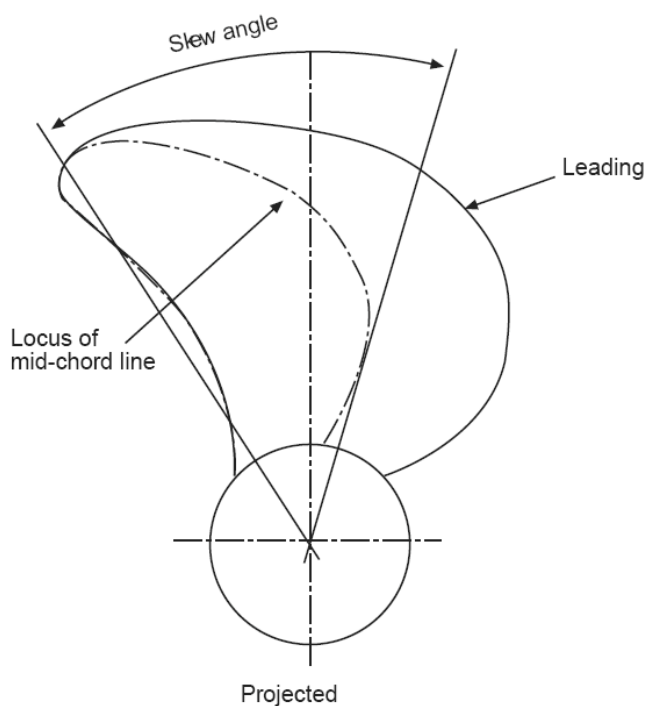


Fig.2 Definition of skew angle

12.2 Severity zones

In order to relate the degree of inspection to the criticality of defects in propeller blades and to help reduce the risk of failure by fatigue cracking after repair, propeller blades are divided into the three zones designated A, B and C.

Zone A is the region carrying the highest operating stresses and which, therefore, requires the highest degree of inspection. Generally, the blade thicknesses are greatest in this area giving the greatest degree of restraint in repair welds and this in turn leads to the highest residual stresses in and around any repair welds. High residual tensile stresses frequently lead to fatigue cracking during subsequent service so that relief of these stresses by heat treatment is essential for any welds made in this zone. Welding is generally not permitted in Zone A and will only be allowed after special consideration by the Classification Society. Every effort should be made to rectify a propeller which is either defective or damaged in this area without recourse to welding even to the extent of reducing the scantlings, if this is acceptable. If a repair using welding is agreed, postweld stress relief heat treatment is mandatory.

Zone B is a region where the operation stresses may be high. Welding should preferably be avoided but generally is allowed subject to prior approval from the Classification Society. Complete details of the defect / damage and the intended repair procedure are to be submitted for each instance in order to obtain such approval.

Zone C is a region in which the operation stresses are low and where the blade thicknesses are relatively small so that repair welding is safer and, if made in accordance with an approved procedure is freely permitted.

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12.2.1 Low-skew propellers

Zone A is in the area on the pressure side of the blade, from and including the fillet to $0,4R$, and bounded on either side by lines at a distance $0,15$ times the chord length C_r from the leading edge and $0,2$ times C_r from the trailing edge, respectively (see Fig. 3).

Where the hub radius (R_b) exceeds $0,27R$, the other boundary of zone A is to be increased to $1,5R_b$.

Zone A also includes the parts of the separate cast propeller hub which lie in the area of the windows as described in Fig. 5 and the flange and fillet area of controllable pitch and built-up propeller blades as described in Fig. 6.

Zone B is on the pressure side the remaining area up to $0,7R$ and on the suction side the area from the fillet to $0,7R$ (see Fig. 2).

Zone C is the area outside $0,7R$ on both sides of the blade. It also includes the surface of the hub of a monobloc propeller and all the surfaces of the hub of a controllable pitch propeller other than those designated Zone A above.

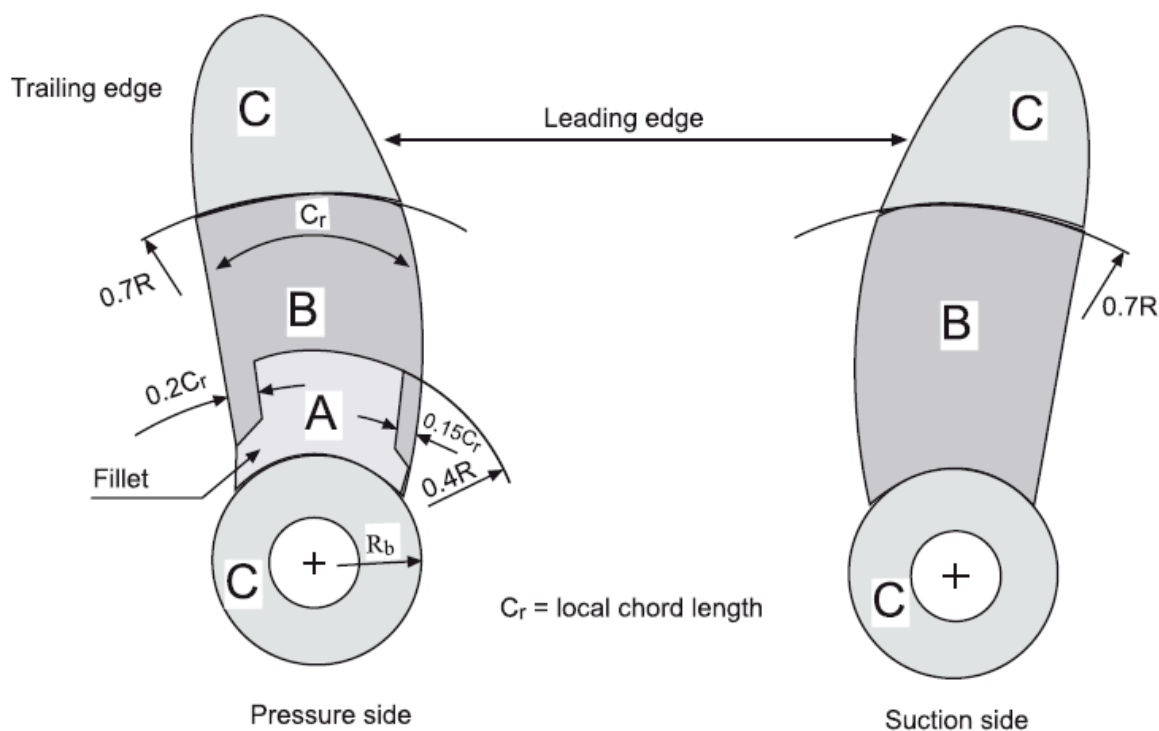


Fig.3 Severity zones for integrally cast low skew propellers

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12.2.2 High-skew propellers

Zone A is the area on the pressure face contained within the blade root-fillet and a line running from the junction of the leading edge with the root fillet to the trailing edge at $0.9R$ and at passing through the mid-point of the blade chord at $0.7R$ and a point situated at 0.3 of the chord length from the leading edge at $0.4R$. It also includes an area along the trailing edge on the suction side of the blade from the root to $0.9R$ and with its inner boundary at 0.15 of the chord lengths from the trailing edge.

Zone B constitutes the whole of the remaining blade surfaces.

Zone A and B are illustrated in Fig. 4.

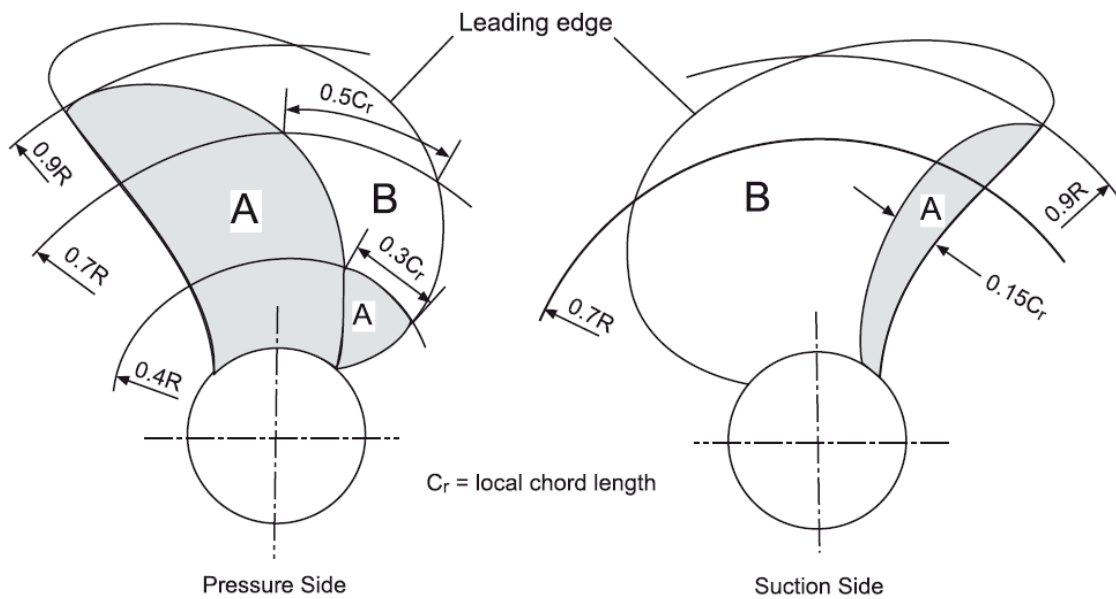


Fig.4 Severity zones in blades with skew angles greater than 25°

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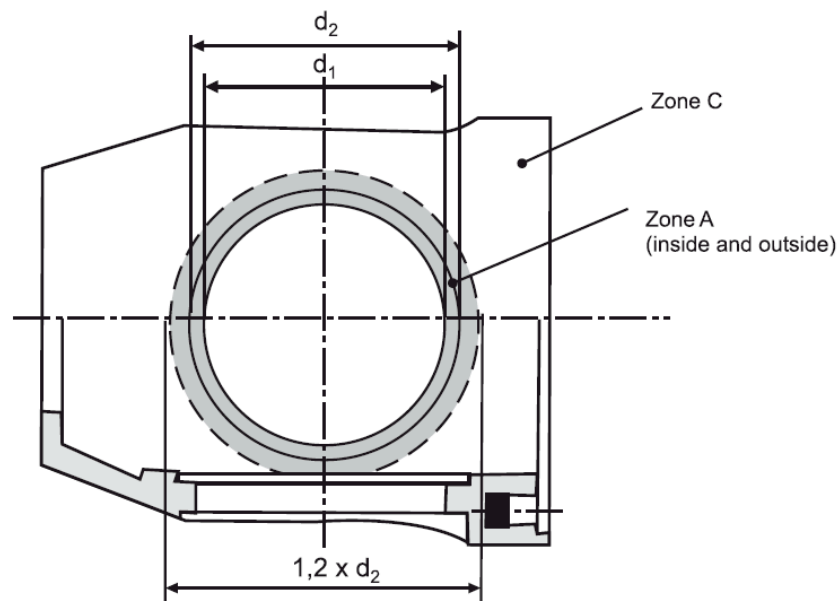


Fig.5 Severity zones for controllable pitch propeller boss

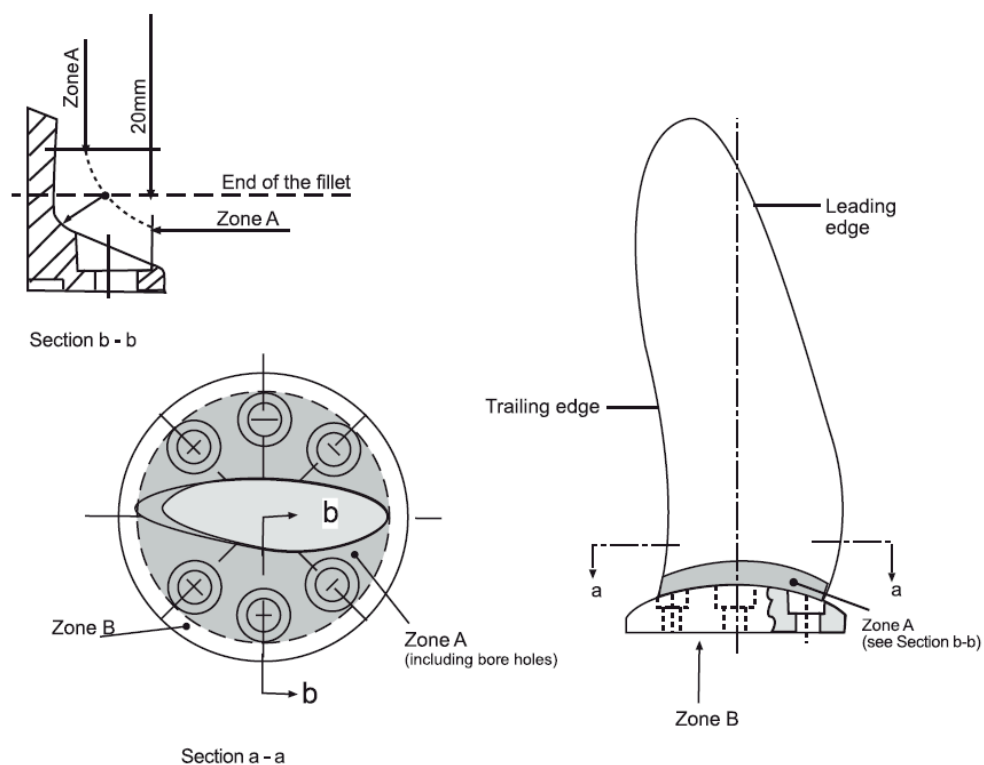


Fig.6 Severity zones for controllable pitch and built-up propeller

Note:

The remaining surface of the propeller blades is to be divided into the severity zones as given for solid cast propellers (cf. Fig. 3 and Fig. 4)

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13. Acceptance criteria for dye penetrant inspection

13.1 Inspection procedure

The dye penetrant inspection is to be carried out in accordance with a standard or specification approved by the Society.

13.2 Definitions

Indication:

In the dye penetrant inspection an indication is the presence of detectable bleed-out of the penetrant liquid from the material discontinuities appearing at least 10 minutes after the developer has been applied.

Shape of indications:

A distinction is made between circular, linear and aligned indications, see Fig. 7.

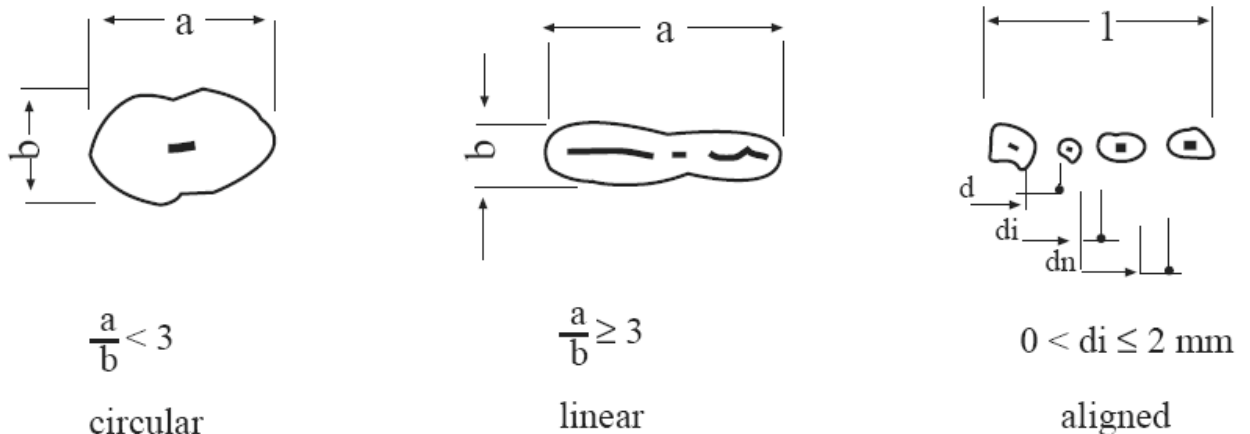


Fig.7 Shape of indications

Reference area:

The reference area is defined as an area of 100 cm² which may be square or rectangular with the major dimension not exceeding 250 mm.

13.3 Acceptance standard

13.3.1 For the judgement, the surface to be inspected is to be divided into reference areas of 100 cm² as given in the definitions, see para 13.2. The indications detected may, with respect to their size and number, not exceed the values given in the Table 3.

The area shall be taken in the most unfavourable location relative to the indication being evaluated.

13.3.2 Areas which are prepared for welding are independent of their location always to be assessed according to zone A. The same applies to the welded areas after being finished machined and/or grinded.

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Table 3 Allowable number and size of indications in a reference area of 100 cm², depending on severity zones

Severity zones	Max. total number of indications	Type of indication	Max. number of each type ¹⁾²⁾	Max. acceptable value for "a" or "l" of indications [mm]
A	7	Circular	5	4
		Linear	2	3
		Aligned	2	3
B	14	Circular	10	6
		Linear	4	6
		Aligned	4	6
C	20	Circular	14	8
		Linear	6	6
		Aligned	6	6
Notes: ¹⁾ Singular circular indications less than 2 mm for zone A and less than 3 mm for the other zones may be disregarded.				
²⁾ The total number of circular indications may be increased to the max. total number, or part thereof, represented by the absence of linear/aligned indications.				

14. Repair of defects

14.1 Definition

Indications exceeding the acceptance standard of Table 3, cracks, shrinkage cavities, sand, slag and other non-metallic inclusions, blow holes and other discontinuities which may impair the safe service of the propeller are defined as defects and must be repaired.

14.2 Repair procedures

14.2.1 In general the repairs shall be carried out by mechanical means, e. g. by grinding, chipping or milling. Welding may be applied subject to the agreement of the Society's Surveyor if the requirements of the paras 14.3, 14.4 and / or 14.5 will be complied with.

14.2.2 After milling or chipping grinding is to be applied for such defects which are not to be welded. Grinding is to be carried out in such a manner that the contour of the ground depression is as smooth as possible in order to avoid stress concentrations or to minimise cavitation corrosion.

14.2.3 Welding of areas less than 5 cm² is to be avoided.

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14.3 Repair of defects in zone A

14.3.1 In zone A, repair welding will generally not be allowed unless specially approved by the Classification Society.

14.3.2 Grinding may be carried out to an extent which maintains the blade thickness of the approved drawing.

14.3.3 The possible repair of defects which are deeper than those referred to above is to be considered by the classification Society.

14.4 Repair of defects in zone B

14.4.1 Defects that are not deeper than $dB = (t/40)$ mm ($t = \text{min. local thickness in mm according to the Rules}$) or 2 mm (whichever is greatest) below min. local thickness according to the Rules should be removed by grinding.

14.4.2 Those defects that are deeper than allowable for removal by grinding may be repaired by welding.

14.5 Repair of defects in zone C

In zone C, repair welds are generally permitted.

15. Repair Welding

15.1 General requirements

15.1.1 Companies wishing to carry out welding work on propellers must have at their disposal the necessary workshops, lifting gear, welding equipment, preheating and, where necessary, annealing facilities, testing devices as well as certified welders and expert welding supervisors to enable them to perform the work properly. Proof shall be furnished to the Surveyor that these conditions are satisfied before welding work begins.

15.1.2 The company concerned shall prepare and submit to the classification Society a detailed welding specification covering the weld preparation, welding procedure, filler metals, preheating and post weld heat treatment and inspection procedures.

15.1.3 Before welding is started, Welding Procedure Qualification Test are to be carried out and witnessed by the Surveyors. Each welder / operator is to demonstrate his ability to carry out the proposed welding using the same process, consumable and position which are to be used in actual repair (the scope of tests is given in Appendix A).

15.2 Welding preparation

Defects to be repaired by welding are to be ground to sound material according to the requirements as given under para 14.2. To ensure complete removal of the defects the ground areas are to be examined by dye penetrant methods in the presence of the Surveyor. The welding grooves are to be prepared in such a manner which will allow a good fusion of the groove bottom.

15.3 Welding repair procedure

15.3.1 Metal arc welding is recommended for all types of repair on bronze propellers.

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For material thickness less than 30 mm, gas welding may give a satisfactory weldment for CU 1 and CU 2 materials.

Arc welding with coated electrodes and gas-shielded metal arc process (GMAW) are generally to be applied. Argon-shielded tungsten welding (GTAW) should be used with care due to the higher specific heat input of this process.

Recommended filler metals, pre-heating and stress relieving temperatures are listed in Table 4.

15.3.2 Adequate pre-heating is to be carried out with care to avoid local overheating, c. f. Table 4.

15.3.3 All propeller alloys are generally to be welded in down-hand (flat) position. Where this cannot be done, gas-shielded metal arc welding should be carried out. The section to be welded is to be clean and dry. Flux-coated electrodes are to be dried before welding according to the maker's instructions. To minimize distortion and the risk of cracking, interpass temperatures are to be kept low. This is especially the case with CU 3 alloys. Slag, undercuts and other defects are to be removed before depositing the next run.

15.3.4 All welding work is to be carried out preferably in the shop free from draughts and influence of the weather.

15.3.5 With the exception of alloy CU 3 (Ni-Al-bronze) all weld repairs are to be stress relief heat treated, in order to avoid stress corrosion cracking. However, stress relief heat treatment of alloy Cu 3 propeller castings may be required after major repairs in zone B (and specially approved welding in Zone A) or if a welding consumable susceptible to stress corrosion cracking is used. In such cases the propeller is to be either stress relief heat treated in the temperature 450 to 500°C or annealed in the temperature range 650-800°C, depending on the extent of repair, c. f. Table 4.

15.3.6 The soaking times for stress relief heat treatment of copper alloy propellers should be in accordance with Table 5. The heating and cooling is to be carried out slowly under controlled conditions. The cooling rate after any stress relieving heat treatment shall not exceed 50°C/h until the temperature of 200°C is reached.

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Table 4 Recommended filler metals and heat treatments

Alloy type	Filler metal	Preheat temperature °C [min]	Interpass temperature °C [max]	Stress relief temperature °C	Hot straightening temperature °C
CU1	Al-bronze ¹⁾ Mn-bronze	150	300	350-500	500-800
CU2	Al-bronze Ni-Mn-bronze	150	300	350-550	500-800
CU3	Al-bronze Ni-Al-bronze ²⁾ Mn-Al-bronze	50	250	450-500	700-900
CU4	Mn-Al-bronze	100	300	450-600	700-850
Notes:	¹⁾ Ni-Al-bronze and Mn-Al-bronze are acceptable. ²⁾ Stress relieving not required, if filler metal Ni-Al-bronze is used.				

Table 5 Soaking times for stress relief heat treatment of copper alloy propellers

Stress relief temperature [°C]	Alloy grade CU1 and CU2		Alloy grade CU3 and CU4	
	Hours per 25 mm thickness	Max. recommended total time hours	Hours per 25 mm thickness	Max. recommended total time hours
350	5	15	-	-
400	1	5	-	-
450	1/2	2	5	15
500	1/4	1	1	5
550	1/4	1/2	1/2 ¹⁾	2 ¹⁾
600	-	-	1/4 ¹⁾	1 ¹⁾
Note: ¹⁾ 550°C and 600°C only applicable for CU 4 alloys.				

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(cont)**16. Straightening**

16.1 Application of load

For hot and cold straightening purposes, static loading only is to be used.

16.2 Hot straightening

Straightening of a bent propeller blade or a pitch modification should be carried out after heating the bent region and approximately 500 mm wide zones on either side of it to the suggested temperature range given in Table 4.

The heating should be slow and uniform and the concentrated flames such as oxy-acetylene and oxy-propane should not be used. Sufficient time should be allowed for the temperature to become fairly uniform through the full thickness of the blade section. The temperature must be maintained within the suggested range throughout the straightening operation. A thermocouple instrument or temperature indicating crayons should be used for measuring the temperature.

16.3 Cold straightening

Cold straightening should be used for minor repairs of tips and edges only. Cold straightening on Cu 1, Cu 2 and Cu 4 bronze should always be followed by a stress relieving heat treatment, see Table 4.

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Appendix A: Welding procedure and welder's qualification test

1 General

The qualification test is to be carried out with the same welding process filler metal, preheating and stress-relieving treatment as those intended applied by the actual repair work.

2 Test sample

A test sample of minimum 30 mm thickness is to be welded in down-hand (flat) position. The test specimens to be prepared and their dimensions are shown in Fig. 8.

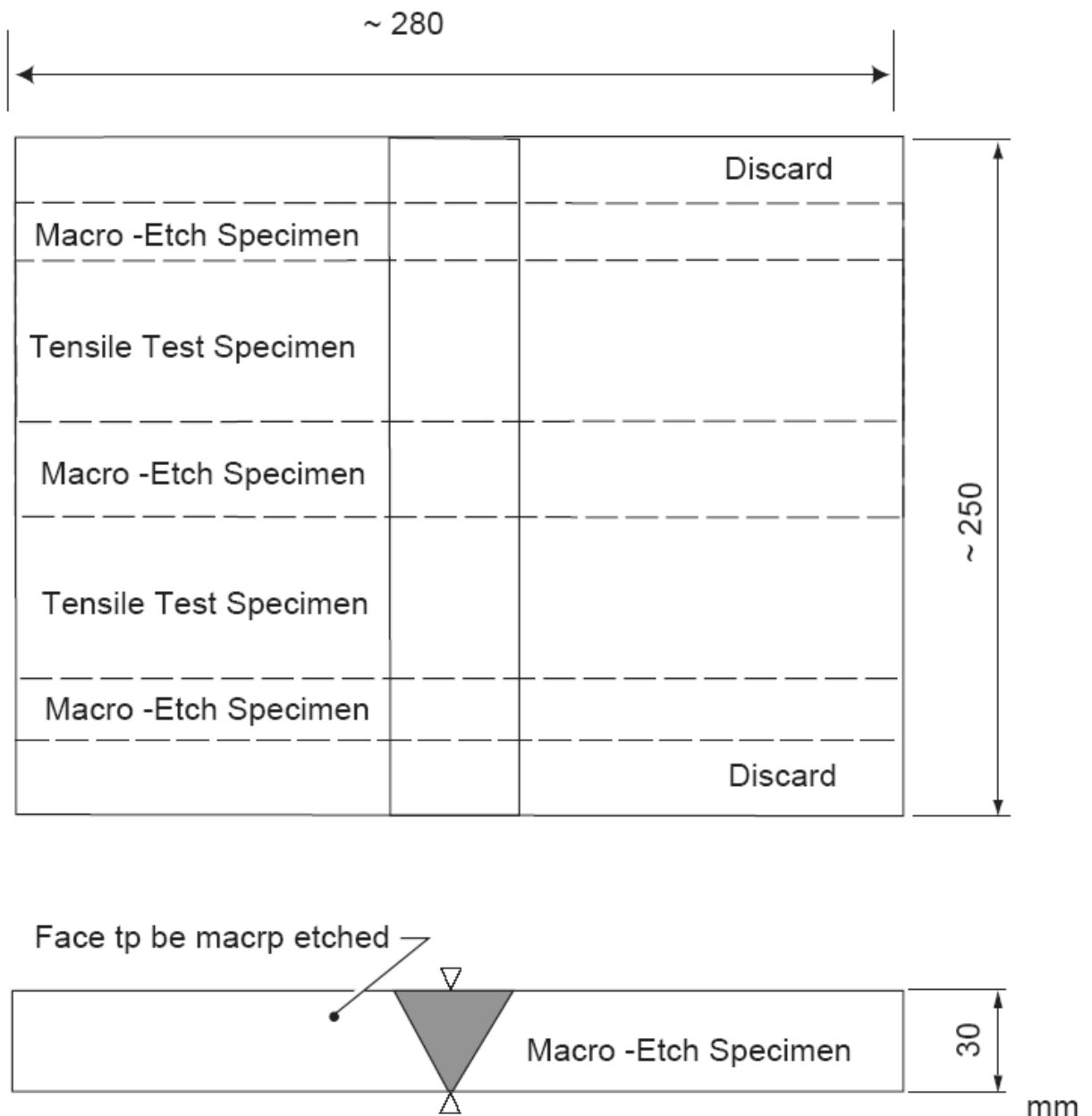


Fig.8 Test Specimen

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(cont)**3 Qualification testing****3.1 Non-destructive testing:**

After completion, the weldment is to be 100% tested by a dye-penetrant method. No cracks are permitted.

3.2 Macro-etching:

Three macro-etch samples should be prepared (see Fig. 8). A suitable etchant for this purpose is:

5 g iron (III) chloride
30 ml hydrochloric acid (cone)
100 ml water.

Pores greater than 3 mm and cracks are not permitted.

3.3 Mechanical testing:

Two tensile tests should be prepared as shown in W2.4.2.8 b). The table requirements to the tensile strength, as given in Table 6, should be met. Alternatively tensile test specimens according to recognized standards may be used.

Table 6 Required tensile strength values

Alloy Type	Tensile Strength, N/mm², min
CU1	370
CU2	410
CU3	500
CU4	550

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