Guideline No.: W-10(201510)

W-10 COPPER ALLOY PROPELLERS

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Foreword:

This Guide is a part of CCS Rules, which contains technical requirements, inspection and testing criteria related to classification and statutory survey of marine products.

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COPPER ALLOY PROPELLERS

1 Application

1.1 This Chapter applies to the integral and fabricated cast copper alloy propellers intended for sea-going and inland waterways ships.

2 Normative references

2.1 The basis for approval and inspection of copper alloy propellers are as follows:

(1) CCS Rules for Materials and Welding

(2) CCS Rules for Classification of Sea-going Steel Ships;

(3) CCS Rules for Construction and Classification of Sea-going High Speed Craft;

(4) ISO 484/1 Shipbuilding-Ship screw propellers-Manufacturing tolerances-Part 1: Propellers of diameter greater than 2.5 m;

(5) ISO 484/2 Shipbuilding-Ship screw propellers-Manufacturing tolerances-Part 2: Propellers of diameter between 0.80 and 2.50 m inclusive;

(6) ISO 3715 Shipbuilding-Ship screw propellers-List of equivalent terms;

(7) ISO 1940-1 Mechanical Vibration-Balance Quality Requirements for Rotors in a Constant (Rigid) State.

3 Definitions

3.1 For the purpose of this Chapter, the definitions given in CCS Rules for Materials and Welding, CCS Rules for Construction and Classification of Sea-going High Speed Craft, CCS Rules for Materials and Welding and ISO 3715 apply.

4 Plans and documents

4.1 A manufacturer (including foundry and machining works) intending for works approval is to submit the following documents to CCS for approval, in addition to those specified in PART ONE of the Guidelines:

(1) type test program;

(2) welding procedure;

(3) drawings and necessary calculations of propellers intended for ships classed with CCS.

4.2 In addition to those in 4.1, the following drawings are to be submitted to CCS for information:

(1) details of products for approval, including alloy type, specification (maximum diameter and maximum mass) and delivery condition;

(2) main production equipment and inspection equipment, including the name/purpose, specification and capacity of smelting, casting and heat treatment equipment, equipment for physico-chemical examination, non-destructive test, metallographic examination (if applicable) and balancing test;

(3) qualification certificates of the personnel engaged in manufacturing and inspection, including at least that for chemical composition analysis, mechanical property test, metallographic examination, non-destructive test, and welding;

(4) a list of raw materials, including main and auxiliary materials.

5 Materials and components

Materials and components are to comply with relevant requirements of CCS Rules

6 Design and technical requirements

6.1 The design and technical requirements for propellers are to at least comply with the requirements of CCS Rules for Classification of Sea-going Steel Ships, Rules for Construction and Classification of Sea-going High Speed Craft, Rules for Construction and Classification of Inland Waterways Steel Ships, and Rules for Materials and Welding.

7 Selection of typical samples

The selection of typical samples for works approval is based on the following requirements:

(1) The typical samples are selected according to the types of copper alloy material, in which Cu3 may cover Cu4, and Cu1and Cu2 may replace each other.

(2) The diameter of at least one alloy type of propellers is to be more than 90% of the maximum diameter of the products for approval, or the mass more than 80% of the maximum mass of the products declared by the manufacturer.

(3) Products manufactured by complicated technology are preferably selected.

8 Type test

The type test items and results are to be carried out according to the following requirements. The typical samples are to be cast according to the requirements in 9.1.5, Section 1, Chapter 9, PART ONE of CCS Rules for Materials and Welding.

(1) Chemical composition analysis: the chemical composition is to be based on the results of product samples analysis. The chemical composition is to comply with the requirements in 9.1.3, Section 1, Chapter 9, PART ONE of CCS Rules for Materials and Welding.

(2) Metallographic examination: the metallographic examination is applicable to propellers made of Cu1 and Cu2. At least one specimen is to be taken from each heat, and the proportion of α phase is to be determined as the average value of 5 counts. The test results are to comply with the requirements in 9.1.3, Section 1, Chapter 9, PART ONE of CCS Rules for Materials and Welding.

(3) Mechanical property test: round proportional tensile test specimens with diameter of 14 mm are to be cut from each test sample in accordance with the requirements given in Item 2 of Table 2.2.2.1 in Chapter 2 of PART ONE of CCS Rules for Materials and Welding. The tensile strength, 0.2% proof strength and elongation are to be determined by mechanical property tests. The test results are to comply with the values given in Table 9.1.6.3, Section 1, Chapter 9, PART ONE of CCS Rules for Materials and Welding.

(4) Visual, dimensional and geometrical tolerances examination: the external quality is to comply with the requirements given in CCS Rules for Materials and Welding. The dimension, dimensional and geometrical tolerances and surface roughness are to be in accordance with the drawings approved by CCS. Where it is not specified, the requirements given in ISO 484 Shipbuilding-Ship screw propellers-Manufacturing Tolerances apply.

(5) Non-destructive test: each propeller and its components are to be subject to NDT in accordance with the relevant requirements in Section 4, Chapter 8 of PART THREE of CCS Rules for Materials and Welding. All propeller castings are to be subject to dye penetration inspections in accordance with three zones A, B, and C. The inspections of Zone A are generally to be carried out in the presence of the Surveyor. Inspections of Zones B and C are to be performed by the manufacturer and a test report is to be submitted to the Surveyor for confirmation, or may be witnessed by the Surveyor as he requires. The NDT results are to comply with the requirements given in Section 4, Chapter 8 of PART THREE of CCS Rules

for Materials and Welding.

(6) Static balancing: static balancing test is to be carried out on all propellers. Indifferent equilibrium test is to be carried out first, then followed by weighing test. The frictional moment of the core shaft of static balancing equipment is not to exceed:

$$M = \frac{G}{2}R$$

where: G - calculated weight suspending;

R - radius of propeller.

The calculated weight suspending is to be in accordance with the drawings approved by CCS. Where it is not specified, the following value is to be taken (whichever is lesser):

$$G = C\frac{m}{Rn^2}$$

$$G = Pm$$

where: G - calculated weight suspending, in kg;

m - mass of propeller, in kg;

R - radius of propeller, in m;

n - running, in rpm;

C and P - coefficient, to be determined according to the running n and grade K:

$C = K$ for $n \geq 180r/\min$;

$C = K \cdot \left(\frac{n}{180}\right)^2$ for $n < 180r/\min$.

The coefficient K is given in the following Table 8(1).

Coefficient k value **Table 8(1)**

Grade of propeller	**S**	**1**	**2**	**3**
K	15	25	40	75
P	0.0005	0.001	0.001	0.001

Where propeller diameter $D \leq 1.5$ m, G is to be calculated by the following formula:

$$G = 0.025\, D^2 + 0.02$$

where: G - calculated weight suspending, in kg;

D - propeller diameter, in m.

Where the works is to manufacture only the components (such as blades) of build-up propellers (such as controllable pitch propeller) without fabrication, and the shipbuilder responsible for fabrication has no static balancing conditions, each blade is to be subject to moment balancing test in the works to determine the balancing moment of gravity center of the blade to propeller axis. For controllable pitch propeller with four blades, the balancing moment of each blade to propeller axis is to meet the following formula:

$$\Delta mi = \left| Wi \cdot Xi - 1/4 \cdot \sum Wi \cdot Xi \right| \leq f\, W / (2.828 + X_n) \cdot N^2$$

where: Wi - mass of number i blade;

Xi - distance between gravity center of number i blade and propeller axis;

N - speed of propeller, in rpm;

Δmi is in kg.m.

The coefficient f is to be taken according to the following Table 8(2):

Coefficient f value **Table 8(2)**

Grade of propeller	S	1	2	3
f	9	12.5	20	37.5

(7) Dynamic balancing: dynamic balancing is generally required for propellers running above 500 rpm, and the permissible unbalanced moments are to comply with the drawings approved by CCS. Where it is not specified, the remaining unbalance mass of propellers are not to exceed the value u_{per} calculated by the following formula:

$$u_{per} = 30000 G' m / (\pi\, r\, n)$$

where: u_{per} - permissible unbalanced mass, in g;

G'- balance quality, 16, in mm/s, according to ISO 1940;

m - mass of propeller, in kg;

r - balance radius, 0.8R, in mm;

n- speed of propeller, in rpm.

(8) Pressure test: the components of build-up propellers with hydraulic fluid cylinders are to be subject to pressure test in products survey. The test pressure is to be in accordance with the drawings approved by CCS. Where it is not specified, 1.5 times the working pressure apply.

(9) Weighing test: propellers are to be weighed. The mass tolerance of the first finished product of propeller is generally not to exceed ±4% of theoretical mass. The mass of the second and the subsequent products are determined according to that of the first finished product of propeller, and the mass difference is generally not to exceed ±2% of theoretical mass. The mass difference between left-handed propeller and right-handed propeller is not to be greater than the value determined according to following formula:

$$\Delta G = m\ 2\% + 0.5$$

Where: ΔG — actual mass difference between left-handed propeller and right-handed propeller, in kg;

m — theoretical mass of left-handed propeller and right-handed propeller, in kg.

(10) Repairs of defects: the repairs of propellers are to comply with the requirements in Section 4, Chapter 8, PART THREE of CCS Rules for Materials and Welding. Where the propellers have defects in Table 2 subject to weld repair, a detailed welding procedure specification and areas of repairs are to be submitted to CCS for approval, covering the weld preparation, welding procedure, filler metals, preheating, post-heating and inspection. The welding procedure is to be approved by CCS in advance. Detailed requirements are given in Tables 8(3), 8(4) and 8(5).

Recommended filler metals and heat treatment temperatures **Table 8(3)**

Alloy type	Filler metal	Min preheat temp. (℃)	Max. interpass temp. (℃)	Stress relieving temp. (℃)	Hot straightening temp. (℃)
Cu1	Al-bronze[①] Mn-bronze	150	300	350-500	500-800
Cu2	Al-bronze Ni-Mn-bronze	150	300	350-550	500-800

Continued Table 8(3)

Alloy type	Filler metal	Min preheat temp. (℃)	Max. interpass temp. (℃)	Stress relieving temp. (℃)	Hot straightening temp. (℃)
Cu3	Al-bronze Ni-Al-bronze② Mn-Al-bronze	100	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.

Weld repair region and area **Table 8(4)**

Position of defects	Weld repair	Maximum size of single defect for weld repair S x h (mm^2 x mm)					Total area to be weld repaired
		D≤1.0m	1.0m< D≤1.5 m	1.5m<D≤2.5 m	2.5m< D≤4.0 m	D>4.0m	
Zone A	Generally not allowed	Repair welding is generally subject to special approval by CCS. Where such weld repair is applied, after the welding the stress is to be effectively relieved by heat treatment and tested. The condition for special approval is that the area and depth of the single defect are not to exceed 70% of the maximum size of the single defect permitted in zone B on the pressure face and the total area of defects are not to exceed 3% of the surface area of zone A which is also to be subject to the agreement among relevant parties					
Zone B on the pressure side (B1+B2)	allowed	500x6	1400x7	2500x10	5000x15	7500x15	The total area to be weld repaired for each division on each side is not to exceed 5% of the surface area in the division, but where the total area on one side of a blade doesn't exceed 5% of the area on the side, the total area on zone C on the pressure side or B4 division on suction side and zone C may reach 7%
Zone B from the root to 0.4R on the suction side (B3 division)		700x8	1500x8	2500x10	5000x15	7500x20	
Zone C and zone B from 0.4R to 0.7R on the suction side (B4 division)		700x8	1500x8	4000x10	7500x15	20000x25	
Inside and outside surface of boss		700x8	1000x8	2000x10	4000x15	10000x25	For inside and outside surface of boss, the total area is not to exceed 5% of the surfaces area. For end faces of boss, the total area is not to exceed 10% of the faces
End faces of boss							

Notes: ① B1 division means the zone B within 0.4R on pressure side, B2 division means the remaining of zone B other than B1 division on pressure side.

② The size of propeller in the table is the net size in the drawings and D is diameter of propeller.

③ The size of defect means the size after the defect is removed.

④ The maximum length of a single defect allowed to be weld repaired is not to exceed two times the square root of the area of a single defect.

Stress relief treatment time for copper alloy propellers **Table 8(5)**

Stress relief temperature (℃)	Cu1 and Cu2		Cu3 and Cu4	
	Hours per 25 mm thickness (h)	Max. recommended total time (h)	Hours per 25 mm thickness (h)	Max. recommended total time (h)
350	5	15	-	-
400	1	5	-	-
450	1/2	2	5	15
500	1/4	1	1	5
550	1/4①	1/2①	1/2②	2②
600	-	-	1/4②	1②

Notes: ① Applicable to Cu2 alloys.

② Applicable to Cu4 alloy only.

③ Unless considered otherwise, the stress relief temperature is between 450℃ and 500℃; in case of weld repair of large area, the annealing temperature is to be between 650℃ and 800℃.

④ To prevent crack, Cu3 is not to work within 300℃-500℃, while Cu4 is not to work within 260℃-480℃ or be disposed at 350℃-565℃ for a long time.

⑤ The heating and cooling is to be carried out slowly under controlled conditions. The heating rate is normally not to exceed 100℃/h, and the cooling rate after any stress relieving heat treatment is not to exceed 50℃/h until the temperature of 200℃ is reached.

Where defects exist in typical samples and weld repair is feasible, the weld repair and stress relief heat treatment for specific defects are to be deemed as type test items. Where the welding quality is found unsatisfactory (such as cracks or openings with size over 3 mm) in the test, the test fails. The inspection of weld repair is to be carried out in accordance with 8.4.8, Section 4, Chapter 8, PART THREE of CCS Rules for Materials and Welding.

9 Assessment of welding procedure

The welding procedure for copper alloy propeller is to be subject to approval by CCS. The approval is a general approval according to different materials, welding method, welding position,

welding grooves, preheating and welding conditions (including stress relief heat treatment). The approval is essential for the propeller manufacturer. The approval is not for specific defects of specific propeller, but for butt weld test specimen to check technical conditions of the manufacturer.

The test specimens for approval are down-hand and butt-weld 30mm specimens, as shown in the following figure9(1):

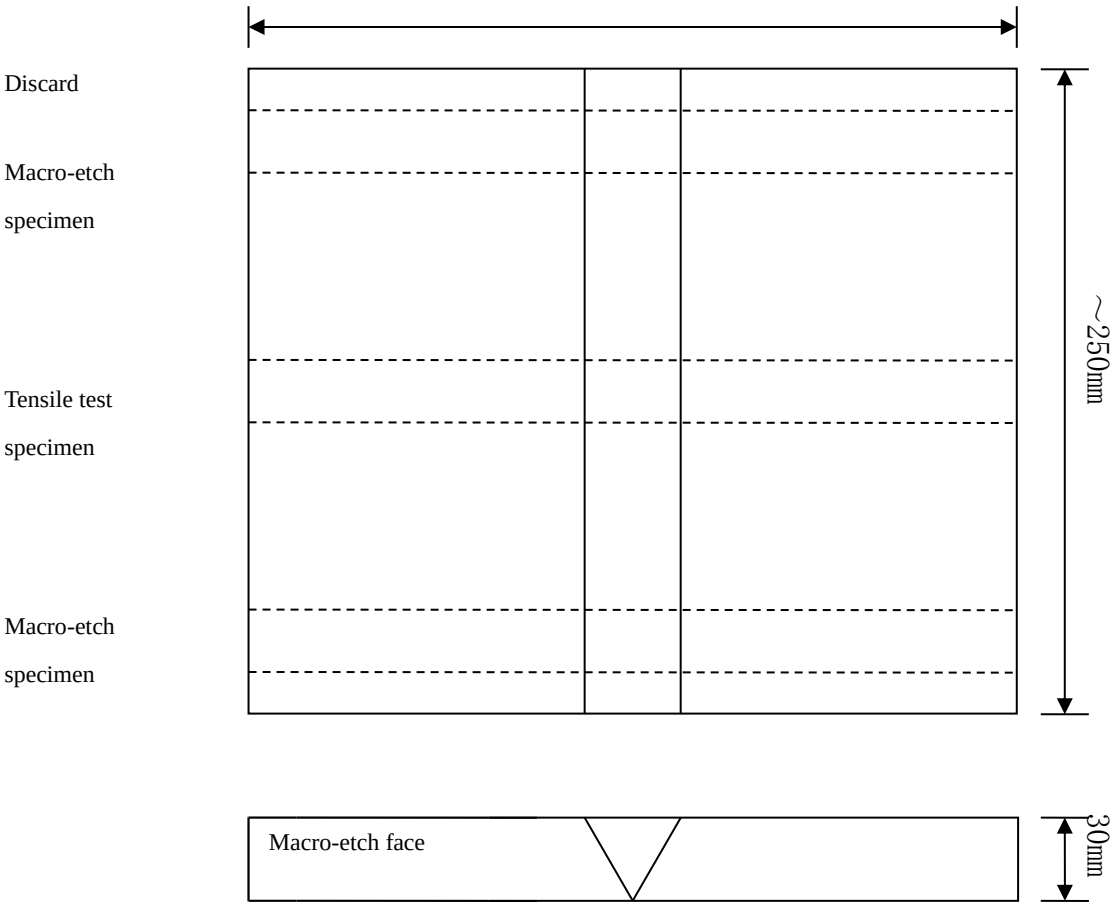

Figure 9(1) The test specimens for WPS approval

The preparation of tensile test specimen is as shown in the following figure 9(2).

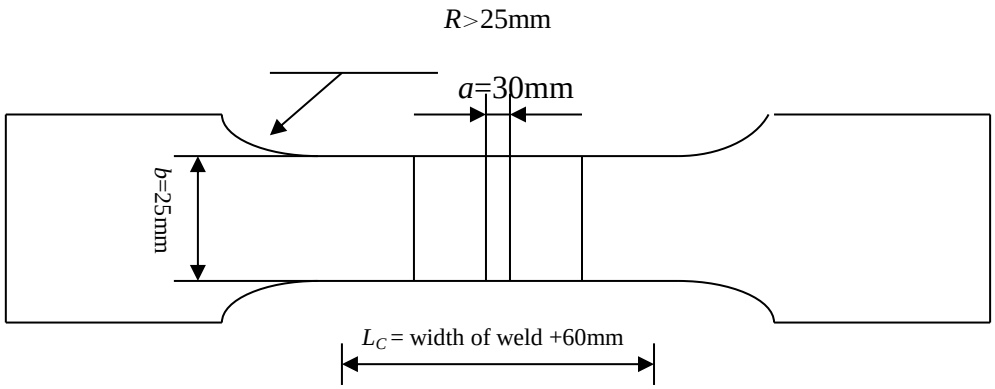

Figure 9(2) Tensile test specimen

The tensile strength of two test specimens is to comply with the requirements in the following Table9(1):

Table 9(1) Tensile strength

Alloy type	**Tensile strength（minimum）N/mm^2**
Cu1	370
Cu2	410
Cu3	500
Cu4	550

Macro-etching: The corrosive liquid for the three macro-etch specimens are to be prepared according to the following proportion:

Ferric trichloride 5 g

Hydrochloric acid 30 ml

Water 100 ml

The macro-etch specimens are to be free from cracks or blowholes exceeding 3 mm.

Non-destructive test: after welding, the welded area is to be subject to dye penetrate and radiographic testing. No cracks or open voids exceeding 3mm are permitted in dye penetrate test. Radiographic test is to be carried out referring to the standard on class II of aluminum pressure vessels in JB 4730-2005. This regulation is not to exclude the adoption of subsequent national or industry standards on ultrasonic testing and radiographic testing.

Welding procedure: in the development of welding procedure, Table 8(3) and Table 8(4) may be used as a guidance to select consumables and determine pre-heating temperature, interpass temperature, post-weld heat treatment temperature and time.

10 Unit/batch inspection

10.1 Each propeller and its components are to be subject to test in accordance with CCS Rules. The following tests are to comply with the requirements of CCS Rules for Materials and Welding and the drawings approved by CCS: chemical composition, matrix structure, mechanical properties, appearance (including surface roughness), size, dimensional tolerance, NDT, static balancing, dynamic balancing (if applicable), pressure (if applicable) and weighing, among which, size, dimensional tolerance, static balancing, dynamic balancing (if applicable), and pressure (if applicable) tests are to be carried out in accordance with 10.8(4), (6), (7), (8) and (9) of this Chapter. The chemical composition and matrix structure may be submitted by the manufacturer to the Surveyor for review. The weighing test in type test of works approval or for the first propeller product may be witnessed by the Surveyor as he requires. The NDT of zone A of propeller is to be in the presence of the Surveyor. For NDT of zones B and C, the manufacturer may submit test report to the Surveyor for review. The remaining items are to be carried out in the presence of the Surveyor. For build-up propellers, static balancing test is to be carried out as much as possible after assembly. For build-up propellers with hydraulic fluid cylinders, the test pressure is to be 1.5 times the working pressure in approved drawings and a tightness test is to be carried out after installation onboard ships with 1.25 times the working pressure.

10.2 After inspection, the manufacturer is to submit quality certificate to the Surveyor for review and as a basis for issue of a certificate of products. The quality certificate is to contain:

(1) name of the purchaser and order number;

(2) vessel identification (if known);

(3) drawing number of propeller;

(4) diameter, number of blades, pitch, direction of turning;

(5) heat number, alloy type and chemical composition;

(6) cast number;

(7) final mass;

(8) NDT methods and result;

(9) proportion of α phase (only applicable to Cu1 and Cu2);

(10) results of the mechanical tests

(11) castings number;

(12) skew angle for high skew propellers;

(13) angle of rake;

(14) static balancing test report;

(15) dynamic balancing test report (if applicable);

(16) pressure test report (if applicable);

(17) measurement report.

10.3 Identification and certification

After survey, each propeller and its components are to be marked by the manufacturer with the following items. For solid propeller, the items are to be marked on the turning face near the small end face of boss and between the two blades.

(1) grade of cast material or corresponding abbreviated designation;

(2) identification of the manufacturer;

(3) heat number, casting number or other marking which will enable the full history of the casting to be traced;

(4) date of final inspection;

(5) CCS certificate number;

(6) ice class notation, if applicable;

(7) skew angle for high skew propellers;

(8) CCS stamp for accepted castings;

(9) mass;

(10) for build-up propellers, in addition to the above items on the surface of the boss, the fillet area of blades are to be marked with serial number of blades and spare blades are to be marked with “BY”. Two digits are to be marked on the end face of blade anchor nut and bolt, the first number being that for blade and the second that for nut or bolt.