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CLASSIFICATION NOTES

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GUIDANCE MANUAL FOR INSPECTION AND REPAIR OF BRONZE PROPELLERS

OCTOBER 1992

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FOREWORD

Det Norske Veritas (DNV) is an autonomous and independent Foundation with the objective of safeguarding life, property and the environment at sea and ashore.

Det Norske Veritas Classification AS (DNVC), a fully owned subsidiary Society of the Foundation, undertakes classification, certification and quality assurance of ships, mobile offshore units, fixed offshore installations facilities and systems, as well as testing and certification of materials and components.

Det Norske Veritas possesses technological capability in a wide range of fields, backed by extensive research and development efforts. The organization is represented world-wide in more than 100 countries.

Classification Notes are publications which give practical information on classification of ships, mobile offshore units, fixed offshore installations and other objects. Examples of design solutions, calculation methods, specifications of test procedures, quality assurance and quality control systems as well as acceptable repair methods for some components are given as interpretations of the more general rule requirements.

An updated list of Classification Notes available is given in the latest edition of the Introduction-booklets to the «Rules for Classification of Ships» and the «Rules for Classification of Mobile Offshore Units».

CHANGES

The Classification Notes 4.1 and 4.2 have been subjected to complete revision. Several amendments have been made, of which «acceptance criteria for surface defects/ indications» and «severity zones of high skew propellers» are new. An appendix concerning «liquid penetrant testing» has also been included. Several minor amendments have been made in order to update and make the Classification Notes more user minded.

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1. Introduction

1.1 General

1.1.1 The purpose of this publication is to recommend methods and guidelines for inspection and repair work of new and used bronze propellers within the frame of the Rules.

1.1.2 Regulations regarding mechanical properties, chemical compositions, testing and inspection, repair of defects, etc. of propeller and propeller blade castings are given in the Rules Pt.2 Ch.2. Rules for propellers in general (scantlings etc.) are given in Pt.4 Ch.2.

1.1.3 The viewpoints and suggested procedures presented in the following represent the considered opinion of Det Norske Veritas. However, other procedures may be considered.

1.1.4 Following ISO Standards may be useful for reference:

- ISO 3715: Equivalent English, French and Russian Terms.
- ISO 484/1: Manufacturing Tolerances — Diameter > 2,5m.
- ISO 484/2: Manufacturing Tolerances — Diameter 0,8—2,5m.

2. Materials

2.1 Chemical composition of propeller bronzes

2.1.1 See Table 2.1.

Table 2.1 Typical chemical compositions of the four most commonly used copper-based propeller materials.

Material	*% Cu*	*% Zn*	*% Fe*	*% Al*	*% Mn*	*% Ni*	*% Sn*
Mn-brass	58	38	1	1	1	0,5	0,5
NiMn-brass	56	34	1,5	1,5	3	3,5	0,5
NiAl-bronze 1)	79,5	—	4,5 2)	9	2,5	4,5 2)	—
MnAl-bronze	75	—	3	8	12	2	—

1) Lead should not exceed 0,03%, otherwise cracking may occur adjacent to welds.

2) It is advisable to keep the Ni-content higher than the Fe-content to prevent formation of iron corrosion products.

2.2 Zinc equivalent

2.2.1 For the Mn-brass and the NiMn-brass, important properties such as ductility and resistance to corrosion fatigue is strongly influenced by the relative proportions of alpha-phase and beta-phase which are the main constituents of the micro-structure in these materials. A too high percentage of beta-phase will adversely affect these properties, and should therefore be avoided. In this connection the concept of the zinc-equivalent is useful since it summarizes the effect of the various chemical elements' tendency to produce beta-phase in the structure.

2.2.2 It is recommended that the zinc equivalent as defined below should not exceed 45%:

$$\text{Zinc equivalent, \%} = 100 - \frac{100 \times \%\ \text{Cu}}{100 + A}$$

where A is the algebraic sum of the following:

$$\begin{array}{rl} 1 & \times\ \%\ \text{Sn} \\ 5 & \times\ \%\ \text{Al} \\ -\ 0{,}5 & \times\ \%\ \text{Mn} \\ -\ 0{,}1 & \times\ \%\ \text{Fe} \\ -\ 2{,}3 & \times\ \%\ \text{Ni} \end{array}$$

The negative contributions from the elements Mn, Fe and Ni indicate that these elements tend to reduce the amount of beta-phase.

2.3 Metallographic determination of alpha-content in Mn-brass and NiMn-brass

2.3.1 The relative proportions of alpha- and beta-phase are not uniquely defined by the chemical composition, but are also affected by the cooling rate from temperatures exceeding approximately 400°C. A slow cooling is required for the alpha-phase to form.

2.3.2 If heat treatment of a part of the propeller has been carried out in connection with welding or otherwise, it may be desirable to determine the alpha-content by metallographic means. In such cases the content of alpha-phase should be greater than 20%.

2.4 Mechanical properties

2.4.1 The mechanical properties specified in the Rules refer to test coupons that in most cases have been cast separately.

2.4.2 The significance of the test coupons should not be overestimated. Their mechanical properties are a measure of the general quality of the metal in each heat. They are not, however, in general representative of the mechanical properties in the propeller casting itself.

2.4.3 This is so because variations in section thickness result in variations in the local cooling rate, which in turn influence the size of grains and precipitates and thus the mechanical properties at any particular location in a casting. The tensile strength of the material from the central regions of heavy sections of a propeller may in practice be up to 30% lower than that of the separately cast test coupon, depending on the dimensions of the propeller.

3. Inspection and non-destructive testing

3.1 General

3.1.1 During inspection of new as well as used propellers, the following should be observed.

3.2 Visual inspection

3.2.1 The propeller should be subjected to a careful visual inspection, particular attention being given to zone A (see 4.1 and 4.2). If undesirable features are seen in this zone, it is recommended that an illuminated magnifier (4—8 times magnification) is employed.

3.2.2 The propeller shall be properly cleaned before the inspection.

3.2.3 It is assumed that propeller geometry and dimensions are controlled by the maker and recorded in a control protocol, which is to be made available for the Surveyor during the inspection. These are to be in accordance with approved drawings within there-in stated tolerances.

Surface finish shall be checked and be in accordance with specification, normally class 1 in the ISO 484.

3.3 Dye-penetrant method

3.3.1 For new propellers, the A-zones (see 4.1 and 4.2) are to be examined by the dye-penetrant method.

3.3.2 When repairs have been made, the repaired area should always be examined by dye-penetrant, regardless of the location of the repair work.

3.3.3 Liquid Penetrant Testing of finally ground/machined propeller blade and hub surfaces shall be carried out in accordance with Appendix B.

3.4 Radiography and Ultrasonic testing

3.4.1 In cases where the number and/or the nature of the defects found on the surface gives reason to believe that serious defects could be hidden under the surface, an ultrasonic inspection should be carried out, keeping in mind the above limitations.

3.4.2 The absorption of the X-rays and gamma-rays is stronger in copper base alloys than in steel. For propeller bronzes, 300 kV X-rays can normally be used up to 50 mm and Co^{60} 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.

3.4.3 As a general rule, ultrasonic testing of Mn-bronze and NiMn-bronze is not feasible, due to the high damping capacity of these materials. For NiAl-bronze and MnAl-bronze, ultrasonic inspection of subsurface defects is possible.

3.5 Recording of observed defects

3.5.1 The location of all defects that are to be repaired should be adequately recorded, preferably on drawings, by those carrying out the repair work. These records should be presented to the Surveyor upon request.

3.5.2 The report is to include a description of non-destructive testing methods used.

4. Severity zones

The propeller is divided into three zones, A, B and C corresponding to the degree of harmfulness of defects.

4.1 Non-skewed propellers

Zone A is the area on the pressure side of the blade, from and including the fillet to 0,4 R, but min. 1,5 R_b (radius of hub), and bounded on either side by lines at a distance 0,15 times the chord length from the leading edge and the trailing edge, respectively. See Fig. 4.1.

Zone A also includes the parts of the separately cast propeller hub which lie between the bores for the blade flanges including the bore surfaces, and the whole surface of the flanges on the separately cast blades. See Figs. 4.3 and 4.4.

Zone B is on the pressure side the remaining area up to 0,7 R, and on the suction side the area from the fillet to 0,7 R. See Fig. 4.1.

Zone C is the area outside 0,7 R of the propeller blade, and the surface of the hub on integrally cast propeller, the remaining part of separately cast hub, in both cases including the bore surface. See Figs. 4.1—4.3.

Zone S covers sealing surfaces between blade flange and hub collar (CP-propellers).

4.2 Skewed propellers

In general, all areas of a propeller blade where tension stresses exceed the stresses in the blade root area (zone A) are to be considered as zone A. Such areas shall preferably be defined in the classification drawings.

For practical use, when the zone A is not given in the drawings, the following may be applied:

Zone A area is extended to include the whole root area at the pressure side and the area around the trailing edge to 0,9 R, measured 20% of blade width at the pressure side and 10% at the suction side respectively. See Fig. 4.2.

Zone B is extended to 0,8R on the pressure side.

A propeller is in this purpose considered skewed, when the trailing edge forms an inward bow exceeding 10% of the blade width measured perpendicularly to the «trailing edge cord line». See Fig. 4.2.

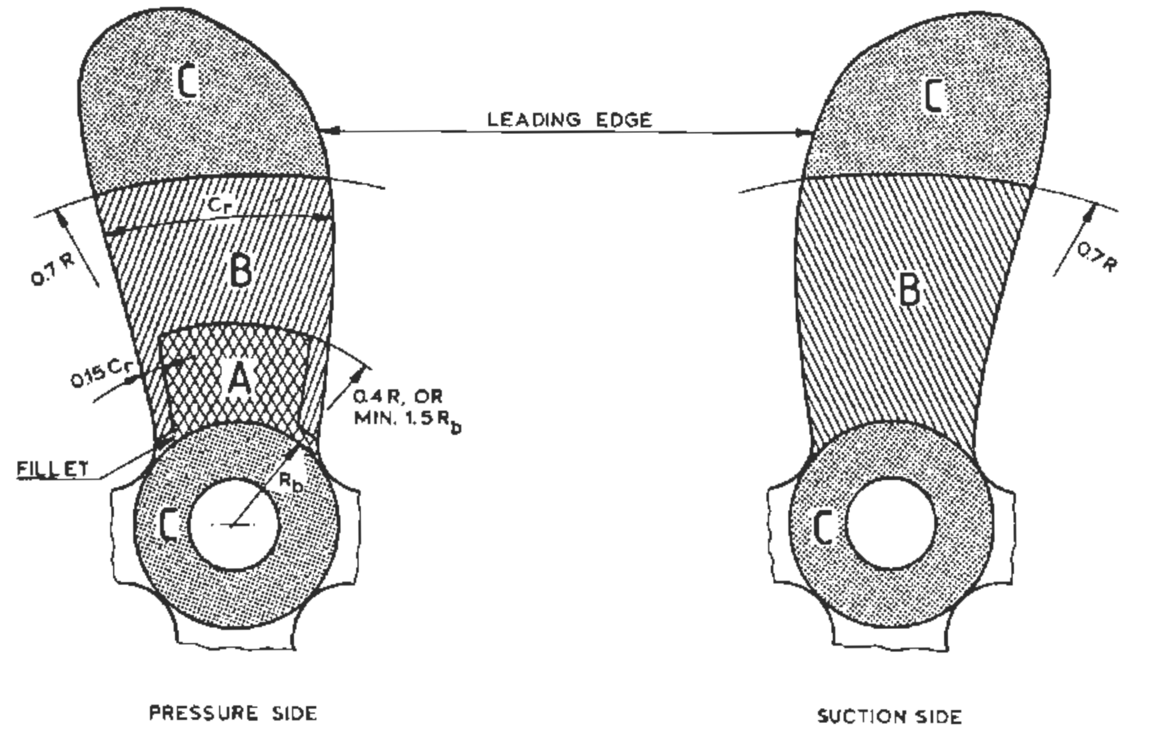

Fig. 4.1
Severity zones — integrally cast propeller.
R = propeller radius.
C_r = chord length at any radius r.

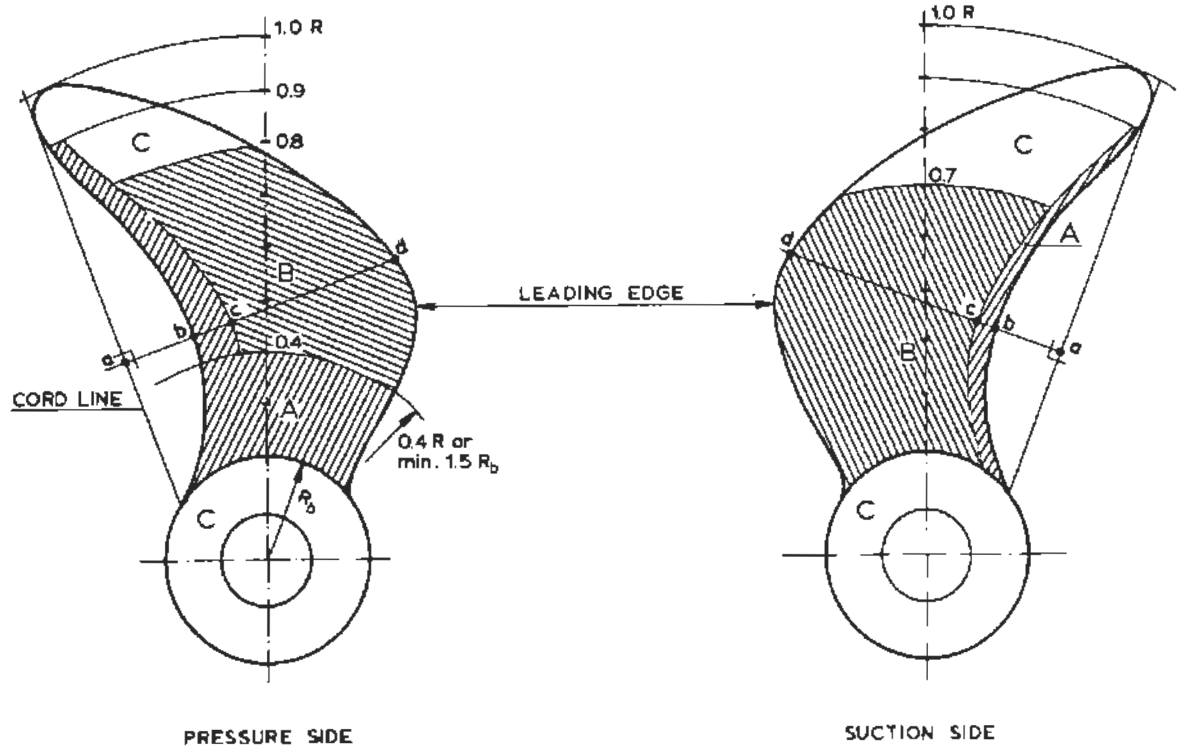

Fig. 4.2
Severity zones — integrally cast skewed propeller.
Valid if a—b > 10% of b—d.

Note: For measurement of b—c the blade width may be taken as shortest distance between the blade edges.

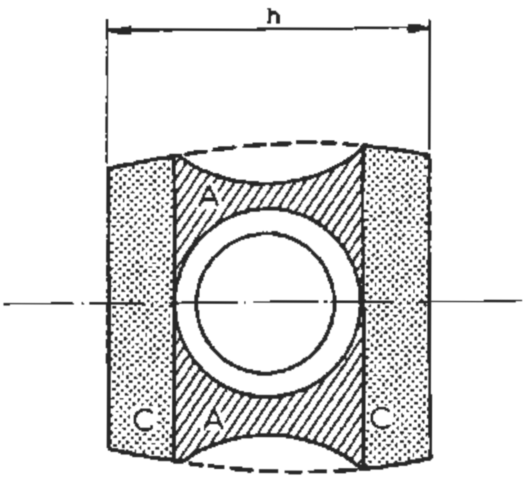

Fig. 4.3
Severity zones — controllable pitch propeller.

Note: Zone S in way of sealing surfaces for blades.

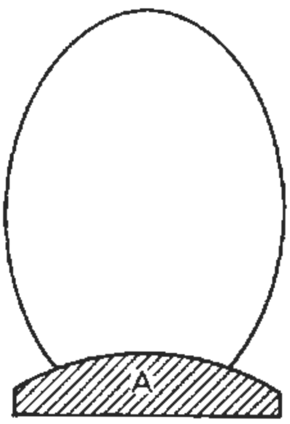

Fig. 4.4
Severity zones — controllable pitch and built up propeller.
For the blade sides, see Figs. 4.1 and 4.2.

Note: Zone S in way of sealing surfaces.

5. Acceptance criteria

5.1 Scope

5.1.1 The acceptance criteria outlined is based on surface inspection of propellers by liquid penetrant. The acceptance criteria refer to «indications» detected by liquid penetrant and is based on normal practice and the quality that can normally be obtained in the production of bronze propellers.

5.2 Liquid penetrant inspection

5.2.1 The liquid penetrant inspection should be carried out in accordance with the procedure given in Appendix B.

5.3 Assessment of result

5.3.1 Definitions:

Indication: In liquid penetrant inspection, «indication» is the presence of detectable bleed-out of liquid penetrant from the material discontinuities.

The indications are normally divided into three different groups that are defined as follows:

Circular shaped: A circular/eliptical indication in which the length is less than 3 times the width.

Linear: An indication in which the length is equal to or greater than 3 times the width.

In-line/aligned: Group of indications consisting of two or more linear indications where the major dimensions are aligned, or four or more circular indications aligned. To be considered as aligned indications, the spacing between each individual indication is not to exceed 2mm.

5.3.2 Evaluation of indications:

The indications revealed in the liquid penetrant testing shall be classified according to 5.3.1 and assessed against the acceptance criteria given in Table 5.1.

Indications which are in doubt must be retested.

5.4 Acceptance standard

5.4.1 Reference area:

The indications shall be judged in a reference area of 1 dm^2 This area may be a square or a rectangle with a major dimension of maximum 250 mm.

5.4.2 Acceptable indications:

Acceptable indications in different severity zones are to be in accordance with Table 5.1. However, no cracks are allowed on finished machined propeller blades.

Table 5.1 Allowable number and size of indications in a reference area of 100 cm^2, depending on severity zones.

Severity zones	*Max. total number of indications* 1)	*Type of indication*	*Max. number of each type* 2)	*Max. acceptable diameter/length of indications (mm)*
A	10	Circular	7	4
		Linear	—	—
		Aligned	3	4
B	20	Circular	14	6
		Linear	—	—
		Aligned	6	6
C	20	Circular	14	8
		Linear	6 3)	6
		Aligned	6 3)	6
S	12	Circular	12	1
		Linear	—	—
		Aligned	—	—

1) Single circular indications less than 2,0 mm shall not be taken into consideration except zone S.

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.

3) Of the 20 indications allowed in the reference area, 6 may be linear *or* aligned.

6. Repair of defects

6.1 Defects

6.1.1 Criteria for acceptable defects are given in clause 5.4 above. All other defects are normally to be removed or repaired by welding.

6.1.2 Removal of surface defects by grinding, and repair of defective castings by welding are subjected to the Surveyor's consent.

6.2 Repair of defects in zone A

6.2.1 In zone A, repair welding will normally not be allowed.

6.2.2 Defects that are not deeper than $d_A = (t/50)$ mm (t = min. local thickness in mm, according to the Rules) or 2mm (whichever is greatest) below min. local thickness according to the Rules, should be removed by grinding.

6.2.3 The grinding should be carried out as described in 6.5.1. The grinding operation should always be followed by a visual and non-destructive examination to ensure that the defect has been completely removed.

6.2.4 The possible repair of defects that are deeper than those referred to above is to be considered by the Surveyor in each separate case. However, edge cracks in used highly skewed propellers may generally be repaired by welding.

6.3 Repair of defects in zone B

6.3.1 Defects that are not deeper than $d_B = (t/40)$ mm (t = min. local thickness in mm, according to the Rules) or 2mm (whichever is greatest) below min. local thickness according to the Rules, should be removed by grinding as described in 6.5.

6.3.2 Repair welding of small defects for the sake of appearance should be avoided.

6.3.3 Those defects that are deeper than allowable for removal by grinding may be repaired by welding. The extent of such repairs, however, should be limited, and their depth should not exceed t/3.

6.3.4 The possible repair of defects that are deeper than those referred to above is to be considered by the Surveyor in each separate case.

6.3.5 The repair welding should be made in accordance with the recommendations set out in clause 7 and to the satisfaction of the Surveyor.

6.4 Repair of defects in zone C

6.4.1 In zone C, weld repairs are generally permitted. The repair welding should be made in accordance with the recommendations set out in clause 7 and to the satisfaction of the Surveyor.

6.4.2 Welds in the bore surface, not in contact with sea water and therefore not prone to stress-corrosion cracking, need not be stress-relieved.

6.4.3 For weld repairs on the outer surface of the boss, and particularly for repairs between the blade fillet areas, care should be exercised to avoid cracking due to thermal stresses in connection with the welding.

6.5 Removal of defects

6.5.1 Defects should be removed by grinding, milling or chipping. The two latter ways of removing defects should always be followed by grinding. The grinding operation should be carried out with moderate grinding pressure and with a high-speed grinding machine, in order to avoid smearing. A defect masked in this way will often remain undetected during the subsequent dye-penetrant inspection.

6.5.2 It is essential that the contour of the ground depression is as smooth as possible so as not to cause stress concentrations or to stimulate cavitation-erosion.

6.6 Edge cracks

6.6.1 Experience has shown that cracks, no matter how small, that begin in an edge are dangerous. Such a crack is an effective stress raiser, and should the propeller receive a blow, a large portion of the blade could be lost, where in the absence of the crack it would only have been bent. It is important, therefore, to eliminate any edge cracks by a proper repair procedure.

7. Repair welding

7.1 General

7.1.1 When defects are to be repaired by welding, the propeller should be in a horizontal position in order to ensure the best conditions for the work to be done. This means that used propellers should be removed from the shaft for repair welds to be made.

7.1.2 For minor repairs, however, welding may be carried out with the propeller on the shaft, provided that the repair is made by a propeller manufacturer or a recognized repair agency. In this context, minor repairs include the repair of edges and adjacent areas outside 0,7 R. Whenever such repairs are carried out, adequate protection from draft and weather should be provided.

7.1.3 Repair of Mn-brass and NiMn-brass propellers on the shaft presents many practical difficulties and should not be attempted unless it is possible to take the necessary precautions. It should be realized that improper welding may be much more harmful than removal of the defect by grinding. Welding with the propeller on the shaft should therefore be regarded as a last resort only.

7.2 Qualification tests

7.2.1 Successful repair of bronze propellers requires considerable experience and skill, not only as to the welding operation, but also regarding the preheating and post-weld stress-relieving procedures which are of decisive importance for the final result.

7.2.2 Manufacturers intending to repair bronze propellers by welding may be requested to carry out a procedure qualification test, as well as an operator qualification test for the welders, for each type of propeller bronze to be welded.

For details of the weld test, which is the same for both types of testing, see Appendix A.

7.3 Preparation for welding

7.3.1 Defects to be repaired are to be ground to sound material according to the recommendations given in 6.5. To ensure complete removal of defects, the ground surface should be examined by dye-penetrant method. Recommended grooves and bevels are shown in Figs. 7.1 and 7.2.

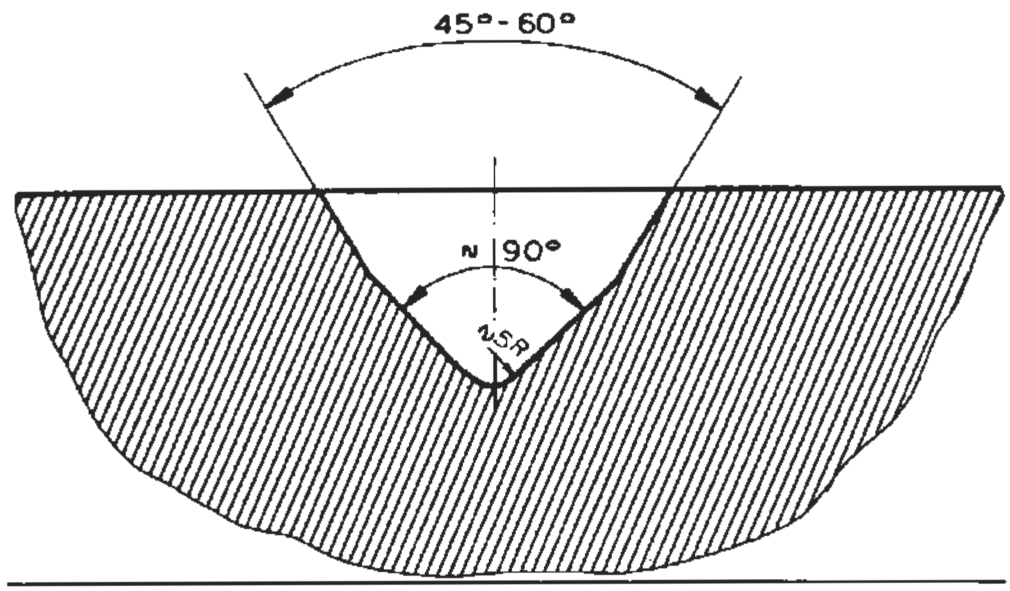

Fig. 7.1
Repair welding — typical groove preparation.

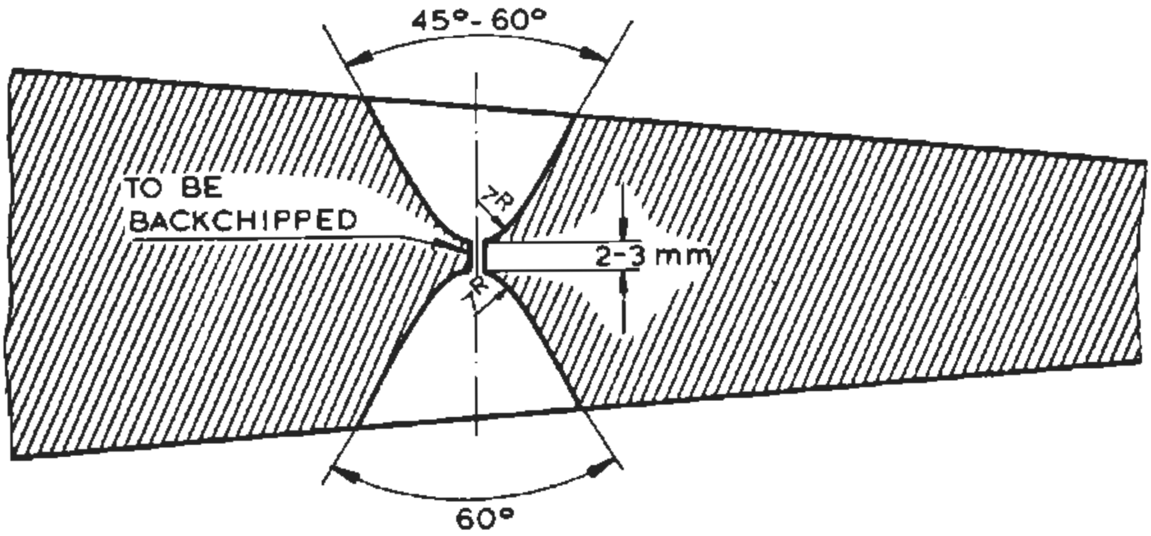

Fig. 7.2
Tip repair — typical preparation of joint.

7.4 Removal of propeller from shaft

7.4.1 Heating of the propeller boss to aid dismounting or fitting of the propeller should be mild and the temperature should not be allowed to exceed 150°C. Concentrated sources of heat (see also 7.5) should not be used. Suitable sources of heat in this connection are steam and electric strip heaters.

7.4.2 Many cases are on record of Mn-brass bosses that have cracked as a result of the misapplication of heat to facilitate removal of the propeller from the shaft.

7.4.3 The use of solid carbon-dioxide («dry ice»), held in place by layers of sacking around the exposed shaft fore and aft of the boss, is a safe and usually effective way of loosening a tight propeller.

7.5 Heat treatment

7.5.1 General:

Both Mn-brass, NiMn-brass and MnAl-bronze are susceptible to stress-corrosion cracking, and it is therefore essential that a stress-relieving heat treatment of these materials is carried out following the repair work in parts of a propeller which will be exposed to sea water.

Heating procedures: A proper heating procedure, whether this may be a preheating or a stress relieving operation, must be followed with care. This implies a slow heating so that the heat may spread evenly through the entire section.

High tensile brass: When a blade edge has been heated locally to any temperature above 300°C, high internal stresses are created on either side of the heated area on cooling to nor-

mal temperatures. A too fast cooling from this temperature results in an unfavourable distribution of alpha- and beta-phase.

It has since long been known that brass has a strong tendency to stress corrosion or self-cracking. A slow and controlled cooling is the only remedy for avoiding cracking as slow cooling gives the alpha-phase time to form.

In these circumstances, Mn-brass is liable to suffer stress-corrosion cracking in sea water, owing to the cojoint action of these high internal stresses with a corrosive element in sea water. It is not unusual to see curved cracks running from blade edges round areas that have been locally heated for repair. This type of cracking may occur within 3 months of immersion in sea water, but if stresses are low it may take as long as a year or more before cracks appear. These cracks can only be avoided if the locally heated blade is correctly stress-relieved immediately after repair.

If stresses are introduced over a large area of blade, including the repair, that blade should be heated to a minimum temperature of 350°C, slowly and uniformly, ensuring that the boundary of the heated area is more or less straight across the blade. The blade should then cool slowly, covered with insulating blankets.

NiAl-bronze: NiAl-bronze is practically immune to stress-corrosion cracking (SCC), and this problem needs not be considered during repairs. The problem with this grade of bronze is the embrittlement experienced between 200 and 500°C.

This is why one rather takes the small risk of SCC than the considerable risk of cracking during stress-relief heat treatment. If a stress-relief heat treatment is required, a temperature of 675°C should be applied.

7.5.2 Preheating:

Heating prior to welding should be carried out carefully to avoid local overheating. Electric resistance heating (strip heaters) are recommended along with mild gas torches. Oxy-propane and oxy-acetylene torches give too concentrated heat and should therefore be avoided.

It is important that the temperature extends entirely through the thickness of the region being repaired, as well as through a 300 mm wide zone adjacent to that region. The heated zone should be chosen so that thermal expansion and subsequent contraction of the heated region can take place as freely as possible. For repairs within 0,7 R, this will often involve a heated zone that extends fully across the width of the blade.

The temperature should be measured by a thermocouple instrument.

Once the appropriate temperature range is reached, the temperature should be maintained within this range until the welding is completed.

After welding, the propeller should be allowed to cool slowly to 100°C.

The preheat temperatures recommended for the various bronzes and welding procedures are listed in Table 7.1.

7.5.3 Stress-relieving:

Heat treatment for stress-relieving purposes may be done by heating the entire propeller in a furnace or by local heating of the repaired area. The first mentioned process offers more uniform conditions and better control and is therefore recommended.

Local stress-relief may be performed by heating slowly, using soft gas torches or electrical strip heaters to the appropriate temperature range. For local stress-relieving, the heating procedure and the zone to be heated are as for preheating, see 7.5.2.

The holding time at prescribed temperature should be 20 minutes per 25 mm section thickness with a maximum of 4 hours.

Cooling from the stress-relieving temperature should be suitably controlled to give time for the correct microstructure to form and to avoid build-up of residual stresses.

In order to accomplish a slow rate of cooling after local stress-relief, wrapping of the heated zone in asbestos blankets or similar should be employed. During the stress-relief treatment, necessary support should be provided for the propeller blades.

The recommended temperature ranges for stress-relief of the various bronze materials are given in Table 7.1.

The temperature should be measured by a thermocouple instrument.

7.6 Welding methods and procedures

7.6.1 Welding methods:

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

For material thicknesses less than 30 mm, gas welding may give a satisfactory weldment for Mn-brass and NiMn-brass.

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

Recommended filler metals, preheating and stress-relieving temperatures are listed in Table 7.1.

7.6.2 Welding procedure:

All bronze alloys should preferably be welded in down-hand (flat) position. Where this cannot be done, MIG welding is preferred.

The section to be welded is to be clean and dry. Flux-coated electrodes should be heated before welding according to the maker's instructions.

To minimize distortion and the risk of cracking, interpass temperature should be kept low. This is especially the case with NiAl-bronze.

Care should be taken to remove slag from undercuts or other defects before depositing the subsequent runs.

Recommended filler metals are listed in Table 7.1.

Table 7.1 Welding processes, filler metals and heat treatments.

Alloy	*Filler metal*	*Preheat temp. °C*	*Stress relief temp. °C*
Mn-brass	Al-bronze * Mn-bronze	150—250	350—550
NiMn-brass	Al-bronze NiMn-bronze	150—250	350—550
NiAl-bronze	Al-bronze NiAl-bronze MnAl-bronze	50—150	None
MnAl-bronze	MnAl-bronze	100—250	450—600

* NiAl-bronze and MnAl-bronze are acceptable.

8. Straightening

8.1 Hot straightening

8.1.1 Straightening of a bent propeller blade should be carried out after heating the bent region and zones on each side of it to the appropriate temperature range given in Table 8.1.

8.1.2 The heating should be slow and uniform, and 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 recommended range throughout the straightening operation. A thermocouple instrument should be used for measuring the temperature.

8.1.3 In order to accomplish a slow rate of cooling after the straightening operation, the heated zone should be wrapped in isolating blankets.

8.2 Cold straightening

8.2.1 Cold straightening should be used for minor repairs of tips and edges only. Cold straightening of Mn-brass, NiMn-brass and MnAl-bronze is always to be followed by a stress-relieving heat treatment (see Table 7.1) due to the susceptibility of these materials to stress-corrosion cracking.

8.3 Application of load

8.3.1 Dynamic as well as static loading may be used in hot straightening. For cold-straightening purposes, static loading only should be used.

Table 8.1 Recommended temperature ranges for hot straightening.

Material	*Straightening temp. °C*
Mn-brass	500—800
NiMn-brass	500—800
NiAl-bronze	700—900
MnAl-bronze	700—850

9. Temporary repairs

9.1 General

9.1.1 Temporary repair of propellers on ships in service may be accepted if a permanent repair cannot be carried out without unreasonable delays and costs. In such cases, a recommendation with respect to reduced RPM (or pitch) and resurvey within comparatively short time may be given by the Society.

9.1.2 In cases of broken propeller blades, the ship may continue sailing for a short period of time, if the opposite blade is removed in such a way that no unbalance occurs in the shaft system.

9.1.3 If a reduction of the RPM is considered necessary in connection with a temporary repair, speed ranges where severe vibrations could occur, should be avoided.

10. Appendix A: Welding procedure and operator qualification test

10.1 General

10.1.1 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.

10.2 Test sample

10.2.1 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 Figs. 10.1 and 10.2.

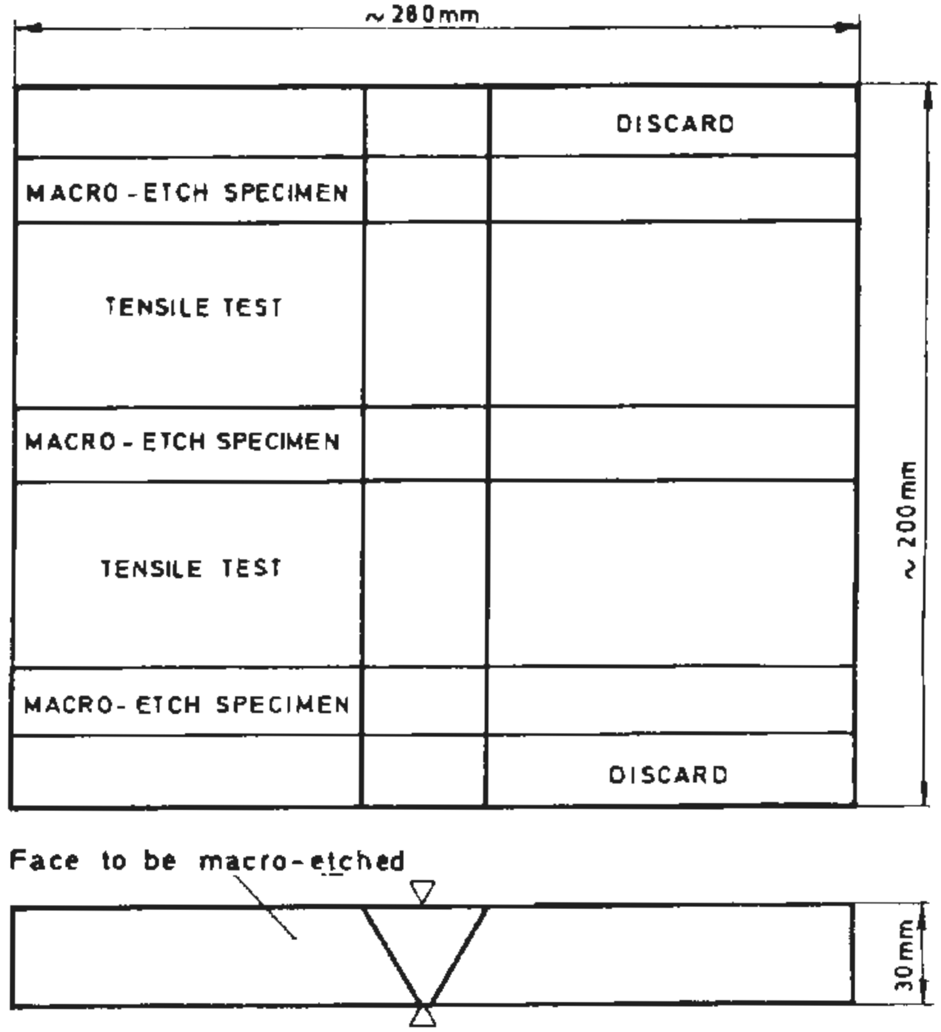

Fig. 10.1
Preparation of test plate.

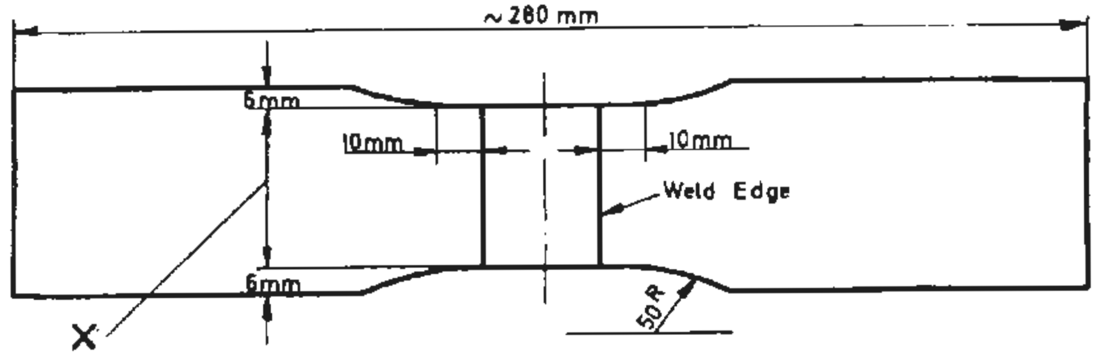

Fig. 10.2
Tensile test.
X is to be determined by the capacity of the tensile testing machine, but is not to be less than 13mm.

10.3 Qualification testing

10.3.1 Non-destructive testing:

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

10.3.2 Macro-etching:

Three macro-etch samples should be prepared (see Fig. 10.1). A suitable etchant for this purpose is:

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

Pores greater than 3mm and cracks are not permitted.

10.3.3 Mechanical testing:

Two tensile tests should be prepared as shown in Fig. 10.2. The requirements to the tensile strength, as given in Table 10.1, should be met.

Table 10.1

Material	*Min. tensile strength, N/mm²*
Mn-brass	370
NiMn-brass	410
NiAl-bronze	490
MnAl-bronze	550

11. Appendix B: Liquid penetrant testing

11.1 General

11.1.1 Application

Liquid penetrant inspection is the best method for detection of all types of cracks, laps, porosity, shrinkage areas, laminations and similar discontinuities open to the surface of nonmagnetic materials, provided proper preconditioning of the surface. The method is also well suited for use on magnetic materials.

11.1.2 Personnel requirement

The manufacturer is responsible for the assignment of skilled personnel to perform the liquid penetrant inspection in accordance with a recognized specification.

11.1.3 Types of penetrant/developer

There are two basic types of liquid penetrants: visible (usually red) and fluorescent. Fluorescent is considered to be the most sensitive. Both types are obtainable for any of the three systems: water washable penetrant, post emulsifying penetrant and solvent removable penetrant. Water washable penetrant is most frequently used.

There are three main types of developer: Dry, water-suspendible, water-soluble and solvent-suspendible developer.

All of the above mentioned types of penetrant/developer may be used for liquid penetrant inspection.

11.2 Description of the process

11.2.1 Surface preparation

The surface must be thoroughly cleaned and dry before it is subjected to liquid penetrant inspection. Discontinuities exposed to the surface must be free from paint, dirt, grease, oil or other contaminants if they are to be detected. To secure a good result the surface roughness of the ground or machined surface should be better than 6,5μm.

11.2.2 Temperature

Too warm or too cold propeller material temperature may lead to unsatisfactory results in the form of poor penetration and/or washing difficulty. The temperature range for liquid penetrant examination should therefore be between 15°C and 50°C.

11.2.3 Penetration

After cleaning liquid penetrant is applied by any suitable means, such as dipping, brushing, or spraying, to form a uniform film of penetrant over the surface. This film should remain long enough to allow maximum penetration of the penetrant. Necessary penetration time depend on penetrant system used and material to be inspected. For bronze materials the penetration time should be in the range 10—30 min.

11.2.4 Removal of excess penetrant

The cleaning method is determined by the type of penetrant used. Some can be wiped off or washed away with water; others require the use of solvents. Uniform removal of excess penetrant is necessary for effective inspection, but overcleaning must be avoided.

11.2.5 Development

A developing agent is applied so that it forms a film over the surface, which will absorb or draw the penetrant entrapped in the discontinuities to the surface. The developer will also provide a uniform background, thereby increasing the flaw visibility.

11.2.6 Inspection

After developing agent has been applied the surface is visually examined for indications of penetrant bleedback from surface openings. The true size and type of discontinuities are difficult to evaluate if the penetrant diffuses excessively into the developer. Consequently, the surface should be closely observed during the application of the developer to monitor the behavior of indications which tend to bleed out excessive. Final interpretation shall be made after allowing the penetrant to bleed out for 7 to 15 minutes.