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MODELLING THE MECHANICAL PROPERTIES OF SCREW PROPELLERS FOR SELECTION OF THE TECHNOLOGY OF THEIR REPAIRS

During repairing screw propellers by welding and plastic deformation it is indispensable to know their material features and strength properties relative to the propeller part subject to repair. The authors have conducted statistical and empirical research aimed at determining those features depending on the propeller's chemical composition and blade thickness. These dependencies are presented in the form of mathematical models useful both cognitively and utilitarian-wise.

Keywords: screw propellers, mechanical properties, technology of repairs.

1. introduction

Damages of screw propellers (fractures, fissure of blades) may occur during the vessels operation. These damages may result from the unfavourable overlapping of the ship's vibrations, screw propeller and propulsion engine. Moreover, some fissures, bends and nicks of the blade rubbing edges might also occur and it frequently happens when the screw propeller strikes against floating beams or ice floes. When the screw propeller works close to the area's bottom, it is worn by the erosion of sand raised from the bottom. Screw propellers are also worn by fatigue corrosion and cavitational erosion. Depending on the kind and extent of damage, location on the propeller and the possibilities of welding or hot straightening, screw propellers are repaired or replaced.

The up-to-date screw propellers are made of highly resistant multicomponent copper alloys, among which there can be distinguished manganese brass (Cu1-category alloys), aluminium brass (Cu2-category alloys), aluminium-nickel bronze (Cu3-category alloys) and manganese-aluminium bronze (Cu4-category alloys).

At present, in each category several kinds of copper alloys screw propellers are produced, and in the case of Cu3 category, even dozens of them, appearing under various trade names. Such a large number of copper alloys produced is the cause why before the screw propeller is repaired the exact chemical composition of the propeller material is not known (frequently the chemical composition of propeller material is protected by patent and constitutes an industrial secret), neither the mechanical properties of the screw propeller are known, in particular the blades with variable thickness of the cylindrical section on the propeller radius; whereas such information is indispensable for selecting suitable parameters and proper repair technology for the screw propeller.

Whereas the chemical composition of the propeller material can be roughly determined without destroying the screw propeller, it is more difficult to determine the mechanical properties of the propeller in places repaired. Taking samples from the propeller blade for determining mechanical properties is out of the question.

The mechanical properties of screw propellers given in technical documentation (certificate) are determined by testing separately cast ingots of 25 mm diameter. The results of this examination are only approximate, and are not the real mechanical properties of the blades of the screw propeller cast, and these can be determined only by taking samples from the screw propeller blade corresponding places.

2. Conditions for the efficient screw propellers repair

The knowledge of real mechanical properties, in particular the plastic properties of propeller blades in the area of repair by hot straightening or welding, permits to select suitable repair parameters (copper alloys of categories Cu1, Cu2, Cu3 and Cu4 have different heating temperatures for the repair of screw propeller blade by hot straightening, as well as welding – Tables 1), facilitates performing the repair, permits the decrease of welding deformation and stress and to avoid possible fissures in the weld and in the HAZ of the welded joint.

Tab. 1. Recommended welding materials and temperatures of thermal treatment at welding and straightening screw propeller blades made of cooper alloys [3]

Alloy category	Welding materials	Minimal preheating temperature [°C]	Maximal temperature between runs[°C]	Temperature of relief annealing [°C]	Temperature of hot straightening [°C]
Cu1	*Aluminium bronze [1] Manganese bronze*	150	300	350-500	350-500
Cu2	*Aluminium bronze Nickel-manganese bronze*	150	300	350-550	350-550
Cu3	*Aluminium bronze Nickel-aluminium bronze [2] Manganese-aluminium bronze*	50	250	450-500	450-500
Cu4	*Manganese-aluminium bronze*	100	300	450-600	450-600

Remarks:
1) Nickel-aluminium and manganese-aluminium bronze can be applied.
2) Relief annealing is not required if nickel-aluminium bronze is applied as welding material.

3. The dependence of the screw propeller mechanical properties in the place of its repair on the blade's thickness

Fragmentary research conducted in the laboratories of screw propeller manufacturers, e.g. the firm LIPS in Holland (a known producer of screw propellers), showed that the properties of screw propeller alloys spread over the propeller blade radius.

This stimulated an attempt to collect measurement data of copper alloys for screw propellers (Table 2) and subjecting them to statistical analysis which showed that the nature of dependences in mechanical properties and increased thickness of the screw propeller cast is best described by regression equation, $WZ\_WM = a + b \cdot lg(W)$ where W – propeller blade thickness in repair place [mm].

The graphic distribution of measurement points in the coordinate system (relative value of mechanical properties– blade thickness, Fig.1) and the lines obtained by way of multiple regression analysis describe fairly well the location of mean result values and suggest that when preparing statistically the measurement data in a common coordinate system – thickness, regression curves can be described by the following equations:

$$WZ(R_m, R_{0,2}, A_5, HB, D_z) = a + b lg(W)$$

where: WZ – relative value of mechanical properties; a- absolute term; W – propeller blade thickness (in repair place) [mm], b – coefficient; D_z – grain diameter.
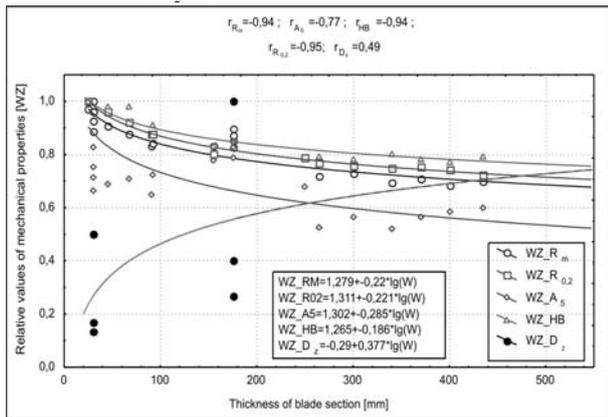

Fig. 1. Dependence of cast properties on the thickness of screw propeller section $WZ\_R_m = R_m/679$; $WZ\_R_{0,2} = R_{0,2}/262$; $WZ\_A_5 = A_5/22.3$; $WZ\_HB = HB/163$; $WZ\_D_z = D_z/0.30$ [4]

Regression curves designated in a common coordinate system show that the changes in the properties of screw propeller cast occur mainly with increased blade thickness in the range from 25 mm to 175 mm and are close to the course of increase in grain diameter D_z; with further screw propeller blade increase, on the other hand, the changes are not very large. This permits the recognition that the deterioration of mechanical properties along with increased thickness of screw propeller blade is due to accompanying grain diameter increase of the copper alloy from which the propeller was cast.

4. The dependence of the screw propeller mechanical properties in the place of its repair on the blade's chemical composition

In order to obtain regression equations, data about mechanical properties and chemical composition of copper alloys from various research centres were collected and compared according to categories. The data concerned screw propellers made by various manufacturers, in various conditions of casting. The casts within the framework of the category had different designations, different chemical compositions and different mechanical properties. The contents of main alloy components in particular categories of copper alloys for screw propellers are presented in Table 2. They are generally in agreement with content differences of components in alloys given by classification societies.

Results of the following model parameters have been obtained (Table 3). In spite of certain deviations in the contents of the main alloy components (Table 2), essential regression equations have been obtained for most cases. Correlation coefficients and the results of Fisher test for checking the essentiality of regression calculated for dependent variables R_m and A_5 have been presented in Table 4.

The fact that R_m correlates stronger (Table 4) with the chemical composition than A_5 results from the measurement technique. The determination of value A_5 depends on the accuracy of comparing both parts of the culled sample.

As shown by Table 4, only regression equations for alloys of category Cu4 with the addition of zinc proved to be non-essential for the value R_m, and possibly incidental for the value A_5. This was probably decided by the overly large discrepancy of zinc content in those alloys ranging from 3.0% to 8.2%, whereas in alloys of other categories the content of particular components is kept within narrower bounds.

Tab. 2. The contents of main alloy components in particular categories of copper alloys for screw propellers

COPPER ALLOYS OF CATEGORY Cu1						
The contents of main alloy components [%]						
Cu	Zn	Al	Mn	Ni	Fe	Sn
58±4.0	37.5±2.5	1.75±1.25	2.25±1.75	0.5±0.5	1.5±1.0	0.75±0.75
COPPER ALLOYS OF CATEGORY Cu2						
The contents of main alloy components [%]						
Cu	Zn	Al	Mn	Ni	Fe	Sn
59±9.0	35.5±2.5	3.03±2.55	2.5±1.5	4.25±3.75	2.75±2.25	0.77±0.72
COPPER ALLOYS OF CATEGORY Cu3						
The contents of main alloy components [%]						
Cu	Zn	Al	Mn	Ni	Fe	Sn
81.80±4.8	0.62±0.37	9.0±2.0	3.25±2.75	2.92±2.67	4.0±2.0	0.2±0.15
COPPER ALLOYS OF CATEGORY Cu4						
The contents of main alloy components [%]						
Cu	Zn	Al	Mn	Ni	Fe	Sn
73.0±10.5	4.35±3.85	7.5±1.5	13.5±6.5	2.0±1.0	4.5±2.5	0.55±0.45

Tab. 3. Regression equations of the model

No.	Copper alloy	Regression equations for particular categories of copper alloys for screw propellers with model parameters
1.	Cu 1	$R_m = -6.931 \cdot c_{Zn} + 61\,241 \cdot c_{Al} - 18\,926 \cdot c_{Mn} - 32\,660 \cdot c_{Ni} - 101\,284 \cdot c_{Fe} - 90\,363 \cdot c_{Sn} + 907\,069$ $A_5 = -0.067 \cdot c_{Zn} + 3.093 \cdot c_{Al} - 3.636 \cdot c_{Mn} - 1.170 \cdot c_{Ni} - 2.043 \cdot c_{Fe} - 5.375 \cdot c_{Sn} + 34.312$
2.	Cu 2	$R_m = 4.595 \cdot c_{Zn} + 43.680 \cdot c_{Al} + 2.154 \cdot c_{Mn} - 10.632 \cdot c_{Ni} - 21.809 \cdot c_{Fe} - 103.980 \cdot c_{Sn} + 442.035$ $A_5 = 0.090 \cdot c_{Zn} - 1.265 \cdot c_{Al} + 0.298 \cdot c_{Mn} + 0.983 \cdot c_{Ni} + 1.521 \cdot c_{Fe} + 12.339 \cdot c_{Sn} + 8.233$
3.	Cu 3 (without Zn and Sn)	$R_m = -63.538 \cdot c_{Al} + 17.021 \cdot c_{Mn} + 12.697 \cdot c_{Ni} + 42.621 \cdot c_{Fe} + 978.803$ $A_5 = -7.277 \cdot c_{Al} + 2.704 \cdot c_{Mn} - 0.977 \cdot c_{Ni} + 4.010 \cdot c_{Fe} + 71.940$
4.	Cu 4 (without Zn and Sn)	$R_m = -63.538 \cdot c_{Al} + 17.021 \cdot c_{Mn} + 12.697 \cdot c_{Ni} + 42.621 \cdot c_{Fe} + 978.803$ $A_5 = -7.277 \cdot c_{Al} + 2.704 \cdot c_{Mn} - 0.977 \cdot c_{Ni} + 4.010 \cdot c_{Fe} + 71.940$
5.	Cu 4 (with Zn but without Sn)	$R_m = -1.612 \cdot c_{Zn} - 2.804 \cdot c_{Al} + 1.383 \cdot c_{Mn} + 14.214 \cdot c_{Ni} - 8.111 \cdot c_{Fe} + 704.306$ $A_5 = -0.037 \cdot c_{Zn} - 1.296 \cdot c_{Al} - 0.444 \cdot c_{Mn} + 1.639 \cdot c_{Ni} + 0.608 \cdot c_{Fe} + 31.704$

Tab. 4. Assessment of regression equations

Copper alloy	Dependent variables	Correlation coefficient	Value of Fisher test	Assessment of regression
Cu1	R_m A_5	0.937 0.909	5.989 3.982	essential essential
Cu2	R_m A_5	0.966 0.906	16.247 5.376	essential essential
Cu3 (without Zn and Sn)	R_m A_5	0.836 0.631	12.179 3.483	essential essential
Cu4 (without Zn and Sn)	R_m A_5	0.870 0.933	7.780 16.903	essential essential
Cu4 (with Zn but without Sn)	R_m A_5	0.806 0.997	0.370 32.597	non-essential incidental

It can be stated on the basis of results obtained that the matching of the model is satisfactory and that the prognostic value of the model high and statistically.

5. Conclusions

In result of statistical calculations conducted, the following conclusions can be drawn:

1. Regression equations of mechanical properties and chemical composition of marine screw propeller casts made of Cu1, Cu2, Cu3 and Cu4 alloys may be essential and permit the modelling the mechanical properties of the propeller with an accuracy sufficient for repair technology.

2. There has been formulated a new, original shape of regression equations of mechanical properties and chemical composition values of screw propeller casts made of copper alloys of categories Cu1, Cu2, Cu3 and Cu4. There are no such equations in the world's literature.

3. Vessel repair technologies have been given a method of modelling the mechanical properties of screw propeller in the blade section being repaired, which will facilitate the preparation of an effective technology (without shrinkage cracks) of repairing the screw propeller by welding or hot straightening of blades.

6. References

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