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EFFECT OF CHEMICAL COMPOSITION AND MICROSTRUCTURE ON MECHANICAL PROPERTIES OF BA1055 BRONZE SAND CASTINGS

ABSTRACT

The effect of the chemical composition of BA1055 bronze on the mechanical properties has been investigated. It is important problem because many ship's sand cast propellers are made of this alloy. Properties of over one hundred melts were analyzed. The metallographic investigations were performed on the samples taken from five sand cast bars. It was shown that even small changes in chemical composition can significantly alter the mechanical properties of BA1055 bronze. The effect of intermetallic κ-phase, i.e. its chemical composition, shape and dimensions of precipitates, seems to be the most important.

Key words: *aluminum bronzes, microstructure, mechanical properties*

INTRODUCTION

The review of the literature [1-7] showed divergent information on the role of intermetallic κ-phase which is compound of such elements like cupper, aluminium, iron and nickel (Fe,Ni,Cu)Al [4], have body centred cubic lattice [3] and is present in the structure of sand cast Al-Ni-Fe bronzes. For example, addition of 4% of Ni to aluminium bronze decreases solubility of Al in Cu from 9.4% to only 4.0% [7]. The released aluminium creates NiAl particles in the structure and enriches κ-phase precipitates. Different opinions concern the amount of iron that can be dissolved in aluminum bronze metal matrix:– up to 3% according to ref. [3] up to 1.43% acc. to [1], or almost without any solubility, only as a component of κ-phase [5]. Increase of iron content in the bronze leads to growth of κ-phase amount and decrease of brittle γ_2 phase. Increase of Fe/Ni ratio cause that precipitates of κ-phase become more spherical. The decrease of Fe/Ni ratio causes that κ-phase precipitates become more lamellar. Also the solubility of Ni in aluminium bronze is differently considered: 0.92% according to ref. [6], up to 2.11% acc. to [1], and almost without any solubility and create NiAl phase [4]. Increase of Ni content in bronze decreases β and γ_2 phases and tends to increase amount of κ-phase. Generally there is still not explained what amounts of Fe and Ni take part in substitutional solid solution formation and what amounts of these elements

are involved in creation of κ-phase in aluminum bronze castings. It is well known that the best mechanical properties of aluminium bronzes can be achieved when iron to nickel ratio in κ-phase is more than 1.0 (Fe/Ni>1)
Providing the explanation of this phenomenon is the main aim of undertaken investigations. The 120 sand castings made of BA1055 bronze were taken into consideration

MATERIAL AND TESTING PROCEDURE

All 120 melts submitted for investigations were delivered in the shape of a separately cast bars 50 mm in diameter, performed parallel with large ship propeller castings. The basic chemical composition of BA1055 (AB2 acc. to BS 1400:1985) bronze is shown in table 1.

Table 1. *Chemical composition of BA1055 bronze (AB2 acc. to BS 1400:1985)*

Bronze	Chemical composition, wt. %								
	Zn max	Pb max	Sn max	Ni	Fe	Al	Mn max	Si max	Mg max
AB2	0,5	0,03	0,1	4,0-5,5	4,0-5,5	8,8-10	3,0	0,1	0,05

Elements of the alloy in the melts were in the range: 9.456÷9.891% Al, 1.015÷1.333% Mn, 4.091÷4.687% Fe and 4.091÷4.807% for Ni.
Mechanical properties depend only on chemical composition of the alloy since technology of melting and cooling rates of all castings were the same. Mechanical properties alter in the range: Yield strength ($R_{0,2}$) 253 - 307 N/mm^2, tensile strength (R_m) 633 - 696 N/mm^2, elongation (A_5) 16.1 - 33.8%, Brinell hardness (HB) 170 – 183 and impact strength measured only on 30 melts (KV) 22.0 - 31.1 J. Both chemical compositions and mechanical properties of all melts meet requirements of BS 1400:1985 standard [8]. Mechanical properties presented above show that factors characterized plasticity of the alloy demonstrate greater scatter than factors describing strength.

The obtained data were analyzed to calculate the correlation between the mechanical properties and the chemical composition of the alloy. The regression method of least sum of squares of the standard deviation was used in the form of two equations, classical and simplified. The classical equations were assumed as:

$$R_m(R_{0.2},A_5) = a + b\cdot Al + c\cdot Mn + d\cdot Fe + e\cdot Ni \qquad (1)$$

and simplified equations in the form:

$$R_m(R_{0.2},A_5) = a + b\cdot Al + c\cdot Mn + d\cdot Fe/Ni \qquad (2)$$

In both equations segment 'a' shows copper influence on mechanical properties of bronze castings while coefficients aside Al, Mn, Fe and Ni show the influence of particular alloying element. Since Fe and Ni are the main components of κ-phase, equation (1) describes amount of κ-phase in the cast structure. Fe/Ni ratio describes mechanical properties of the castings in connection with dimensions and shape of κ-phase, but is not the measure of the amount of this phase in the structure. Fe/Ni is considered as shape coefficient of κ-phase precipitates.
Assessment of simultaneous influence of amount and shape of κ-phase on bronze mechanical properties has been presented in the next equation:

$$R_m(R_{0,2},A_5) = a + b\cdot Al + c\cdot Mn + d\cdot Fe^2/Ni \quad (3)$$

The metallographic observations were performed on samples chose from the set of 120 castings (melts) of BA1055 bronze. Casings were divided according to their mechanical properties and five of them were chosen in the way to cover the whole range of tensile strength. Basic structures were described and quantitative fraction of each phase was established with the use of optical microscope and image analyse MultiScan software.

TEST RESULTS AND DISCUSSION

The obtained regression equations, correlation coefficients, mean standard deviation, Fisher test results for significance checking, probability of incidental result and regression estimations are presented in Table 2.

Table 2. *Results of regression analysis*

Equation	Regression equation	Correlation coefficient	Mean standard deviation %	Fisher test result	Probability of incidental result, %	Estimation of regression
1	**$R_{0,2}$=-602+53.9·Al-11.3·Mn+110.4·Fe-21,9·Ni**	0.871	6.9	5.53	2.5	essential
	R_m=-158+57,5·Al-40,0·Mn+75,0·Fe+0,3·Ni	0.820	6.7	3.60	6.7	essential
	A_5=-182+17,7·Al-5,0·Mn+27,5·Fe-5,7·Ni	0.816	2.3	3.49	3.5	essential
2	**$R_{0,2}$=-344+35,8·Al-54,0·Mn+128,3·Fe/Ni**	0.695	7.0	2.49	13.5	possible
	R_m=-419+2,6·Al+60,6·Mn+160,8·Fe/Ni	0.531	6.6	1.04	42.4	possible
	A_5=-37+0,8·Al-14,7·Mn+74,8·Fe/Ni	0.610	3.9	1.58	26.8	possible
3	**$R_{0,2}$=-697+79,0·Al-5,7·Mn+51,3·Fe-1,2·Fe^2/Ni**	0.846	5.6	4.32	4.2	essential
	R_m=469+14,2·Al-79.1·Mn+31.8·Fe+3,6·Fe^2/Ni	0.748	4.3	2.22	16.8	possible
	A_5=303-25,9·Al-33,8·Mn-8,2·Fe+10,8·Fe^2/Ni	0.832	2.2	3.95	5.5	essential

The regression equations presented in Table 2, according to formula (1) are essential. Equations according to formula (2) show that correlation can be at least possible. This low estimation of regression is probably connected with incomplete description of κ-phase effect on mechanical properties; shape and dimensions of particles were not enough described.

The regression equations according to formula (3) are also essential. In this case κ-phase was well described. Elongation of the alloy seems to be most sensitive to κ-phase shape and dimensions. The influence of κ-phase on yield strength and tensile strength is not such essential.

Metallographic investigations indicated that aluminium in BA1055 bronze occurred in the form of solid solution in α phase and in eutectoid $\alpha+\gamma_2$ (or α+NiAl [4]) and as the constituent associated with iron, nickel and copper in intermetallic κ-phase.

Coefficients of regression equations show that aluminum have the strongest influence on mechanical properties of the BA1055 alloy; increases tensile strength and in lesser extent yield strength, and decreases plasticity of castings. Manganese also increases tensile strength but influence of this element on elongation is weak. Influence of manganese is slight due to small amount of this element in BA1055 alloy. Iron addition considerably increases yield strength and have leaser effect on tensile strength and elongation. Nickel strongly increases yield strength and have negative effect on elongation. Addition of nickel together with iron and manganese to chemical composition of aluminum bronzes relieve the Ni effect on mechanical properties.

Structures of BA1055 bronze is showed in Fig. 1 and 2.

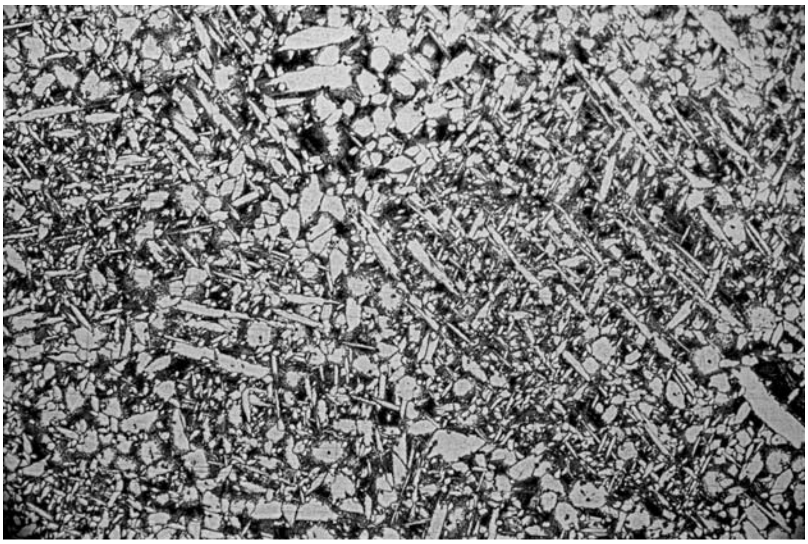

Fig. 1. Microstructure of BA1055 bronze. White grains - α phase, dark fields - eutectoid $\alpha+\gamma_2$, κ-phase – slightly visible. Magn. 200x

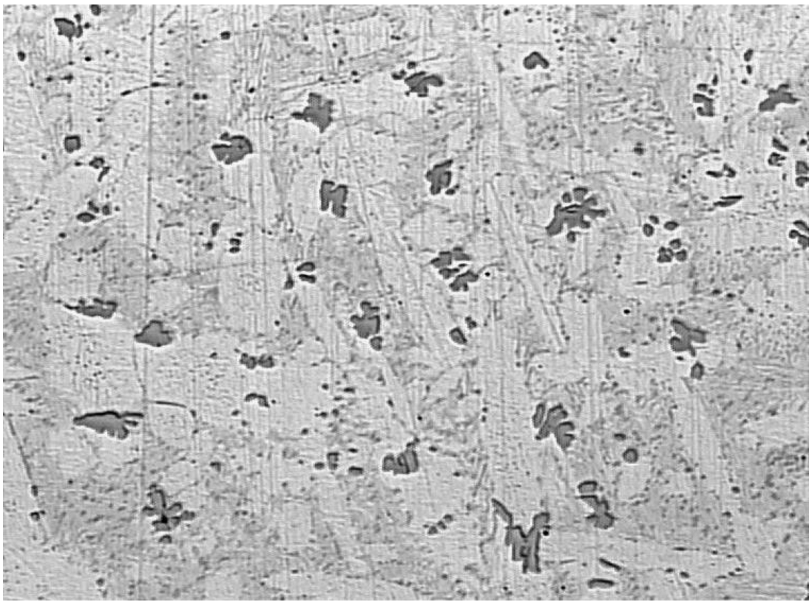

Fig. 2. κ-phase precipitates. Unetched specimen. Magn. 500x

κ-phase is well visible in the Fig.2. This intermetallic phase could appear in four morphologies designated as κ_I , κ_{II} , κ_{III} and κ_{IV}. The κ_I phase is a large dendritic shaped (rosette-like) precipitate. The κ_{II} is also dendritic-shaped, but smaller than κ_I. The κ_{III} precipitates are lamellar or globular eutectoidal decomposition products. The κ_{IV} precipitates are in the form of fine particles (plate like in morphology) of different sizes distributed throughout α grains along certain crystallographic directions [9].

The relationship between tensile strength and amount of structural phases in five chosen castings are shown in Fig. 3-5.

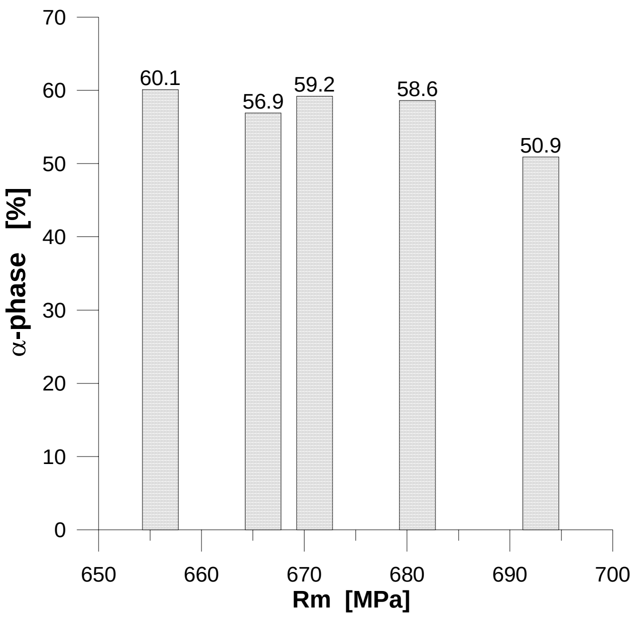

Fig. 3. α -phase contribution in the structure of five casings of BA1055 bronze

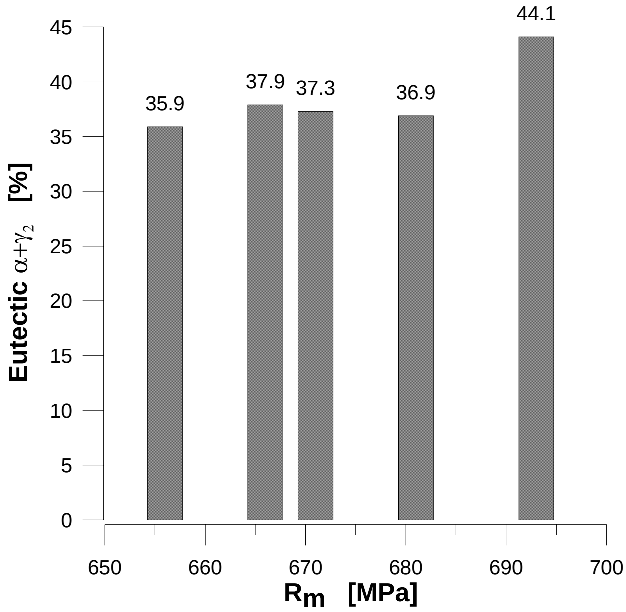

Fig. 4. Eutectoid $\alpha+\gamma_2$ contribution in the structure of five casings of BA1055 bronze

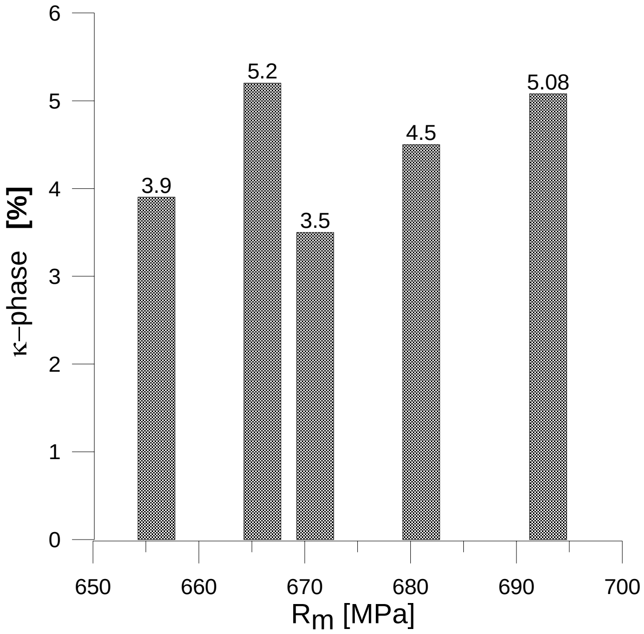

Fig. 5. κ phase contribution in the structure of five casings of BA1055 bronze

Tensile strength of BA1055 castings increases when greater amounts of eutectoid $\alpha+\gamma_2$ occur in alloy microstructure, or with leaser amount of α-phase. The relationship between tensile strength and amount of κ-phase in microstructure was not found (Fig.5). On the other hand it is well known that κ-phase strongly influence the tensile strength in Al-Ni-Fe bronzes. This strengthening effect is obviously connected with morphology of κ-phase (dimensions and shape of precipitates).

CONCLUSIONS

- Regression calculations showed that mechanical properties of BA1055 bronze castings can be predicted with specific probability on the basis of chemical composition of the alloy.
- Higher amount of eutectoid $\alpha+\gamma_2$ in bronze microstructure enhance tensile strength of the alloy.
- The strengthening effect of κ-phase depends not on the amount of this phase in the microstructure, but on its morphology (dimensions and shape of precipitates).

REFERENCES

1. Sokolov N.N., Lazarenko S.R., Żuravlev V.I.: Grebnye vinty iż aluminievoj bronzy. Sudostroenie. Leningrad 1981.
2. Kowarsch A., Zaczek Z.: Miedź i jej stopy w budownictwie okrętowym. Wydawnictwo Morskie. Gdańsk 1989.
3. Prowans S., Wysiecki M.: Wpływ żelaza na strukturę i przemiany fazowe brązów aluminiowych. Archiwum Hutnictwa. Tom XVII, Zeszyt 4, 1972, 379-393.
4. Berezina P.: Gefűgeumwaldungen und mechanische Eigenschaften der Mehrstoff-Aluminiumbronzen vom Typ CuAl10Fe5Ni5. Gisereiforschung, Jg.25,H.3, 1973. 125-234.
5. Berezina P.: Gefűgeumwaldungen und mechanische Eigenschaften der Mehrstoff-Aluminiumbronzen vom Typ CuAl10Fe5Ni5 (Schluss). Giesereiforschung, Jg.25,H.4, 1973, 1-10.
6. Crofts W.J., Towsend D.W., Bates A.P.: Soundness and reproducibility of properties of sand-cast complex aluminium bronzes (BS1400-AB2). The British Foundry man, Vol.57, part 2, 1964.
7. Tuschy E.: Nickel-Aluminium-Bronzen. The International Nickel Company. London 1962.
8. BS1400:1985 Copper alloy ingot and copper alloy and high conductivity copper castings.
9. Al-Hashem A., Raid W.: The role of microstructure of Ni-Al- bronze alloy on its cavitation corrosion behavior in natural seawater. Materials Characterization 48, 2002, 37-41.