NEW CLASS OF COMPOSITE BRONZE, ARMED WITH STEEL DENDRITES FOR ANTIFRICTION TECHNIQUE

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Abstract: *Bronzes type BrZhNA 12-7-1 (12% Fe, 7% Ni, 1% Al) form dendritic structure that consists of a maraging martensitic steel 03N15Yu1 mesh, which arms matrix given bronze with content Cu – base, 5-6% Ni and 1% Al. Dendrites can be strengthen by dispersion hardening. Mass transfer phenomena during crystallization and heat treatment in these bronzes were investigated. This bronze has elevated mechanical and technological properties, low friction coefficient and high wear resistance level during sliding friction.*

Keywords: BRONZE, CRYSTALLIZATION, DENDRITE, COMPOSITE, MASS TRANSFER, MECHANIC PROPERTIES, FRICTION COEFFICIENT, WEAR RESISTANCE

1. Introduction

The widely known bronze BrO10 has high tribological, good casting and mechanical properties, but it is not deformed in the hot state due to the presence in it of brittle intermetallic Cu_3Sn unfavorable form, that do not make possible the control of their properties. Other bronze such as BrA_7, BrB_2, which have a complex of high mechanical and technological properties, are not suitable for using in the sliding friction assemblies, since they do not meet the requirements of Charpy´s rule as they lack of a solid "supporting surface". Regarding this situation, the possibility of creation of bronze, reinforced with maraging steel dendrites of composition 03N15Yu1, whose properties are well known, was considered.

The present work is a continuation and development of researches [1-4] conducted on a group of composite bronzes, differing mainly in the methods of their manufacture, which showed that the production of castings rod (Ø=7 mm, l= 800 mm) by vacuum suction guarantee a speed of crystallization (> 700°C/s) that it is not lower than the crystallization rate from the melted metal. Essentially, it was carried out an experimental modelling of melted metals BrZhNA 12-7-1, BrZhNOA 12-7-2-1 in its pure (ideal) form, in the properties of which, do not affect the technology of welding or casting, and it was examined the structure of the studied alloys and welded joints bronze-bronze, bronze-cast iron and the mechanical and tribological properties of these bronzes.

The purpose of this work - the creation of bronzes, designed for sliding friction assemblies, with an optimal set of mechanical, technological and service properties.

2. Materials and Methods

Experimental bronzes ingots, weighing 3 kg were prepared by melting the pure raw materials in a Tamman furnace in a reducing atmosphere of carbon monoxide in alundum crucible. Ingots, 3 and 7 mm diameter rods, were made of bronze obtained by vacuum suction [5-8] from the melted metal, prepared in the induction furnace (Model API-25), in 3 and 7 mm diameter and 800 mm long quartz tubes. The particular feature of obtaining rods was that the suctioned melted bronze cooled in less than 1s from 1300 to ≈ 600°C (to dark cherry color) in a quartz tube. Crystallization and cooling rate in this temperature range was not less than 700°C/s. In fact, it can be called quenching from the liquid state similar to single-layer casting. Also, the ingots were melted again in argon using the procedure described in detail in [4]. The chemical composition of bronze studied is presented in Table 1.

***Table* 1:** Experimental Bronze Chemical Composition (balance-copper), wt. %

№ Composition	Bronze brands	Fe	Ni	Sn	Al
1	BrZhNA 13-6-1	12,88	5,98	-	1,04
2	BrZhNOA 13-6-2-1	13,5	7,00	1,6	0,98
3	BrZhNA 12-7-1	11,85	7,43	-	0,48
4	BrZhNOA 12-7-2-1	11,30	6,96	2,13	0,79

Notes. 1) Total amount of impurities (Mn, Cr, Si and others) did not exceed 0.5 wt.%. 2) bronzes 1, 2 obtained in ingots, bronzes 3, 4 vacuum suction (vacuum casting).

Local chemical analysis of the structural components of the alloys was performed on a scanning electron microscope Jeol JSM 6490-LV with an attachment for microanalysis Oxford Inca Dry Cool (resolution of 133 eV) with a 3 μm diameter area. Total chemical analysis of alloys was determined with an area of 2 mm^2 by averaging the results of the three measurements from different sites.

Metallographic studies were carried out on the optical (Carl Zeiss Axio Observer) and scanning (Carl Zeiss EVO50) microscopes.

Alloy mechanical characteristics were determined using standard tensile test of tenfold specimens with a gage length diameter 5 ± 0,02 mm at room temperature in an Instron 3382 machine.

Friction coefficient and wear intensity were determined in a special device, mounted on the base of a CNC machine. Testing was carried out by a disk-finger specimen scheme with continuous computer recording of all test parameters (pressure, sliding speed, temperature, friction force). For each alloy were tested three specimens (finger samples of bronze different composition) of size 6 x 6 x12 mm; the counter body was a disk of steel ShKh15 (45 HRC). Tests have a comparative character, that is, the friction coefficient of the alloys was evaluated by comparing with the friction coefficient of the base material, which was a bronze BrO10. Over technique tribological test is described in detail in [3, 9].

Wear was determined by fingerprint method at a pressure of p=1 MPa and sliding speed v = 3,3 m/s in a friction path of 105 m. The wear rate was evaluated as the ratio of wear to the friction path.

Also were investigated two types of melting manufacture: bronze BrZhNA 12.7.1 melted on a BrZhNOA 12-7-2-1 ingot weighing 2 kg (cladding thickness up to 5 mm) and the same bronze melted on a Ø=30 mm rod made of cast iron SCh28, cladding thickness of 6-7 mm. Then the structure of the transition zones, general and local part of the structural components was examined.

3. Results and Discussion

Fig. 1 shows the morphology of the structures of BrZhNA 12-7-1 bronzes, manufactured in different ways: ingot crystallization with speed 15°C/min, casting with speed of a higher order [4], vacuum suction casting, in which the crystallization rate was not less than 700°C/s. In the cast the cross section of steel dendrites is 50-100 μm, and in this same alloy, obtained by melting and the vacuum suction, - more than an order of magnitude lower, but dendritic morphology and dispersion were substantially identical (Fig 1 b, c).

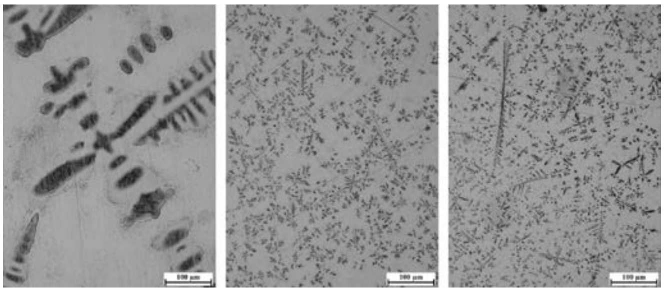

Fig. 1 *BrZhNA 12-7-1 bronzes structure: a) 3 kg cast ingot b) Ø =7 mm casting rod obtained by vacuum suction c) argon arc melting similar bronze thickness 5 mm*

This suggests that the 7 mm diameter rod obtained by vacuum suction, experimentally models melted metal in its purest form. The fact is that the level of mechanical properties of melted metal obtained by conventional means, in a large extent depends on the technology, the conditions and the quality of deposition (defects, the effect of the substrate on which the casting is performed) and qualifications of the performer. The vacuum suction technology also allows to eliminate or significantly reduce the mentioned above negative factors and get the "idealized" melted metal, to which properties should be sought in practice. Mechanical properties of the investigated alloys are shown in Table 2 in comparison with bronze BrO10.

Table 2: Mechanical properties of experimental bronzes depending its manufacturing method.

№	Bronze composition	Mechanical Properties				
		$\sigma_{0,2}$, MPa	$\sigma_в$, MPa	ψ, %	δ, %	δ_p, %
2 – 3 kg ingots, crystallization speed < 15 ºC/min						
1	BrO10	170	215	10-14	3-10	-
2	BrZhNA13-6-1	170	364	42,8	38,2	20,3
3	BrZhNOA13-6-2-1	246	336	10,1	1,2	2,0
Ø=7 mm rods obtained by vacuum suction crystallization speed > 700 ºC/s						
4	BrZhNA 12-7-1	220	295	38,5	16,0	6,4
5	BrZhNOA 12-7-2-1	208	220	18,4	6,7	4,1

Note: Deviation of mechanical properties values from shown values is for ingots - 7% (items 2,3), for rods ≤ 3% (items 4,5)

Its friction coefficient is low in comparison with other bronzes, but it is not welded by melting methods, and has a low level of plasticity. Bronzes, containing about 2% tin (Table. 2, items. 3, 5) have a reduced plasticity (especially low figures of relative elongation), but the level of resistance of these bronzes is higher than those of tin-free bronzes (the effect of solid-solution strengthening copper matrix with tin [10]). They have an unsatisfactory weldability and for electric arc welding methods are not applicable.

Thus, there is reason to consider bronze BrZhNA 12-7-1, obtained by vacuum suction - as "idealized" melted metal. Set of mechanical properties of bronze BrZhNA 12-7-1 (Table 2, item 4) is quite satisfactory: the level of its strength is higher than BrO10 bronze in 30-40%, and plasticity - in 3-4 times.

In [11] it was considered the formation during crystallization process of steel dendrites in bronzes, similar to those we are now considering, and it was shown the dendrite growth in the solid state as a result of the diffusion deposition Ni, Fe, Al from copper matrix to the surface of the dendrite. During casting of the composite bronze on BrZhNOA 12-7-2-1 (Fig. 2) takes place reverse process. Bronze matrix has a melting temperature of 1100°C and in the heat-affected zone at a distance up to 0.8 mm from fusion line in the molten metal steel dendrites partially dissolve (Fig. 2c).

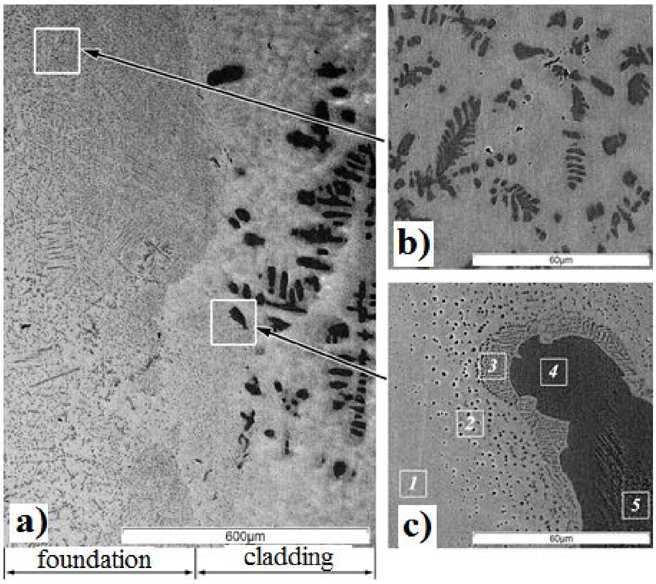

Fig. 2 *Structure particularities of fusion zone in bronze BrZhNA 12-7-1 (cladding) on bronzes BrZhNOA 12-7-2-1 (a); dendrites morphology in the cast (b); dendrite surface dissolving in ingot (c) heat-affected zone.*

This is evidenced by the morphology and chemical analysis of the local zones 1-5 (Table. 3). Matrix, up to its fusion, had the composition of zone 2 (Fig. 2c), after dissolving in the molten matrix, steel dendrite surface and its subsequent crystallization, it is formed zone 3, enriched in Fe and Ni. Thus, the shell (zone 3), follow the contours of the dendrite (zone 4), whose morphology resembles eutectic and consists of a bronze matrix with the composition of the zones 1 and disperse steel inclusions measuring less than 2 μm (for comparison: the size of the primary matrix inclusions (zone 2) formed during the casting crystallization, not less than 5 μm). Such structure is characteristic of the entire heat-affected zone, subjected to melting during casting (Fig. 2a).

Table 3. Dendrite chemical composition in bronze BrZhNOA 12-7-2-1 and adjacent matrix, wt.%

№ zone	Fe	Ni	Al	Sn	Cu
1	1,7	3,4	0,3	4,5	90,3
2	4,9	7,0	0,4	3,1	84,6
3	17,8	10,9	0,6	2,4	68,3
4	54,1	21,9	0,4	-	23,6
5	58,5	18,5	0,3	-	22,8

Next, we consider the possibility of casting the test composite BrZhNA 12-7-1 bronze on cast iron SCh28.

In Fig. 3 it is shown fusion zone of cast iron and bronze. The transition zone 1, formed during the crystallization process on iron base and differs a little in chemical composition of cast iron (Table. 4), however, in this region bronze inclusions can be observed (zone 2-1) and inclusions, close in composition to the dendrites (Fig. 1, c; Table 3, zone 5), but with a different morphology – undetermined (zone 2-3).

Bleached gray cast iron are not observed, what is evidenced by the low micro-hardness of the entire zone 1. Peripheral melted bronze layer is closed, in chemical composition, to its original composition (zone 3-1), however, the inclusions of maraging steels have a globular form instead of a dendritic one (see Fig. 2b).

On the basis of available data, it should be assumed that such a change in the morphology of the steel inclusions in the melted bronze, as we suppose, is due to the presence in it of silicon (zone 3-2), which diffused form cast iron to the entire thickness of the bronze cladding. Formally, we can conclude that precisely silicon prevents the formation of dendrites.

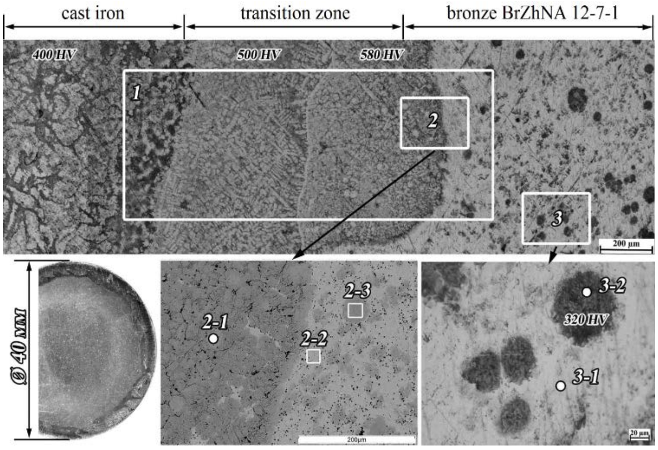

Fig. 3 Transition zone structure and composition during casting bronze BrZhNA12-7-1 on cast iron brand SCh28 (composition shown in table 4).

Table 4: Chemical composition of structural components in melted bronzes BrZhNA 12-7-1 on gray cast iron SCh 28, wt.%

№ zone	Fe	Ni	Al	Si	Cu
1	94,0	0,6	-	2,7	2,7
2-1	70,2	14,1	0,4	1,1	13,2
2-2	3,0	3,1	0,7	0,2	93,0
2-3	68,5	13,6	0,2	1,2	16,
3-1	3,5	3,9	0,7	-	91,9
3-2	70,7	11,5	0,2	1,0	16,7

Thus, during casting on iron the composite bronze, reinforced with steel dendrites of maraging steel ceases to be composite, but conserves satisfactory technological properties.

The results of the friction coefficient measurements of bronze BrZhNA 12-7-1 obtained in many different ways, is shown in Fig. 4, and the wear resistance in Table 5.

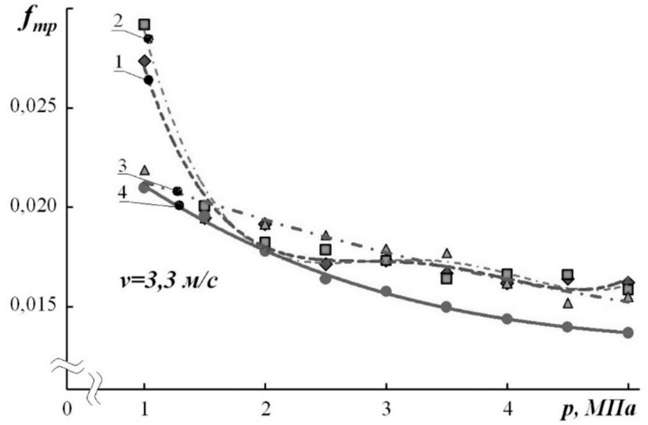

Fig. 4 Bronzes friction coefficient:
1(◆) – BrZhNA12-7-1, argon arc melting; (■) 2 – BrZhNA 12-7-1, obtained by vacuum suction; 3 (▲) – BrZhNA13-6-1 casting; 4 (●) – BrO10 casting.

The results show that: the friction coefficient of bronze BrZhNA 12-7-1 is slightly higher than BrO10 and the friction force values for welding and casting, obtained by vacuum suction, are the same (Figure 4, curves 1 and 2). Wear intensity of experimental bronze BrZhNA 12-7-1 (Table. 5, item 1, 2) is substantially (one order of magnitude) lower than that of similar castings (Table. 5, item 3). This is due to the high dispersion of the dendritic component (Figure 1, b, c.) - the morphology of these states is identical and differs fundamentally from that of the casting (Figure 1, a.). BrO10 bronze wear resistance is also significantly different from the cladding Table. 5, item 4).

These results once again confirmed that the method of casting manufacture by vacuum suction experimental models melted metal, at least for the group of studied experimental bronzes.

4. Conclusions

Our study showed that the experimental composite bronze BrZhNA 12-7-1 may be a good prototype of industrial bronze, designed primarily for casting and welding products and assemblies operating under-sliding friction conditions. The lack of intermetallic compounds of group B and of tin in this bronze guarantees a higher level of mechanical, technological and service properties.

The method of experimental modelling of the melted deposited metal by vacuum suction proposed and justified in the paper enables to get production of castings, ideally corresponding to melted metal.

Preliminary studies have shown that at sliding speeds higher than 6 m/s it is possible to grasp this bronze to the counterbody. However, we have already tested the option of replacing the maraging steel type N16YU1 dendrites by stainless steel dendrites, suggesting that it can contribute to increase the permissible sliding speed.

5. References

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