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MICROSTRUCTURE AND TRIBOLOGICAL PROPERTIES OF TIN BRONZE-GRAPHITE COMPOSITES MADE BY STIR CASTING

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The paper presents results of the studies into production of copper-based composite materials for slide bearings. The studied materials covered tin bronze based composites with addition of lubricating phases in a form of graphite. The composite materials were prepared by melting and casting with simultaneous stirring. The titanium was introduced to the metal matrix in order to improve wettability of the graphite particles. The lowest average value of the coefficient of friction was reached with the CuSn10/graphite 45 μm composite which contained 0,4 % Ti. Low coefficients of friction and wear of the friction pair were also reached with other examined composites in CuSn10 matrix.

Key words: bronze composite materials, bearing materials, stir casting, microstructure, tribological properties

INTRODUCTION

Elimination of harmful to human and environment elements and substances is one of the basic activities of sustainable development strategy. The relevant, increasingly restrictive regulations [1 - 3] address application of toxic substances, including, among others, the use of lead in the widely considered economy. With respect to copper-based metallic materials it involves the necessity to eliminate lead from antifriction materials, which are commonly used in the classical copper alloys intended for bearings and sliding elements [4]. This implies a need to develop new materials and products for the antifriction elements, therefore in many countries there are studies into that subject carried out for some time already.

The composite materials for slide bearings are usually produced by powder metallurgy methods [5 - 9]. The classical metallurgy techniques, based on liquid metal mixing and simultaneous adding of the particles of non-metallic phases followed by centrifugal casting, are also applied [5, 6, 10 - 14].

The area covered in this article included metal matrix composites produced by mixing of solid additives with liquid metal (stir casting). The aim was to determine possibilities of using this method for production of bronze - graphite composites for sliding elements.

MATERIALS AND METHODS

The matrix of composite materials was in a form of CuSn10 and CuSn10P alloys. Pure metals (Cu, Sn) and the preliminary CuP14,7 alloy were used as a feedstock in the process of CuSn10P alloy melting. Melting was carried out in an induction crucible furnace under charcoal cover and then material was cast into heated ingot moulds with a diameter of 35 mm.

The non-metallic "soft" phase particles, providing low friction and self-lubrication, were represented by graphite powder with a particle size of 20 μm and of 45 μm.

In production of composites a method of melting and casting with simultaneous mechanical stirring in the liquid state (stir casting) was used. The manufacturing process was carried out according to the diagram shown in Figure 1, and included: melting of the alloy in an induction crucible furnace, transfer of the metal bath with the crucible to resistance furnace and its homogenization at 1 100 °C, introduction of lubricating phase particles heated to the temperature of 200 °C into the metal bath, mixing of the metal bath with graphite stirrer at constant speed, removal of the crucible with the suspension and casting into a preheated graphite mold. In or-

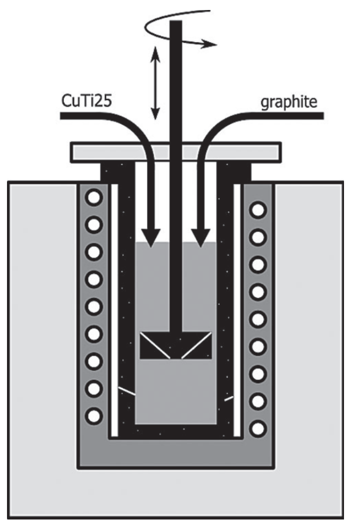

Figure 1 Diagram of production of metal matrix composites by the stir casting method

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der to improve the wettability of the graphite particles titanium was added to the metal matrix.

Characteristics of the microstructure of the examined materials was performed with light microscope Olympus GX71F.

Basic investigations into bearing properties were carried out with CSM Instruments high-temperature THT Pin type Ball-on-Disk tribometer. Observations of wear tracks in the samples were performed with scanning electron microscopy (SEM) using Zeiss Evo MA10 microscope, and to identify the chemical composition in microzones energy-dispersive analysis (EDS) was used with application of EDS Bruker XFlash® 5010 spectrometer.

RESULTS AND DISCUSSION

A representative microstructure of the composite materials is presented in Figure 2. Distribution of non-metallic phase (graphite) was generally uniform over the entire length of the ingot at relatively low tendency to segregation. Only in the case of composites which contained graphite of a particle size of 20 μm agglomerates of non-metallic phase in the metallic matrix were observed.

The tribological properties were evaluated using the „pin-on-disk" method under the conditions recommended by the ASTM G99-05 standard. According to the methodology applied, a sample had a form of a disk, ø 35 × 10 mm in dimensions, the surface of which was subjected to grinding by SiC abrasive paper, grit 600. The counter-sample (pin) was in a form of a steel ball (100 Cr6 steel), 6 mm in diameter. In each test cycle a new sample and counter-sample were used. Prior to each test, the surfaces of the sample (disk) and the counter-sample (pin) were washed with acetone and dried. The tests were performed at a constant load of 10 N, sliding distance was 2 160 m (34 377 laps), sliding speed was 0,5 m/s (477,46 rpm), and the wear track diameter was 20 mm. Dry sliding conditions were applied at a room temperature and humidity of 25 % ± 3 %.

Summary of the results of tribological tests are presented in Table 1, while Figure 3 shows a sample surface of wear track of the examined composites after contact with steel ball together with the results of chemical analysis (EDS) at selected points.

Analysis of the abrasion results showed that the lowest average value of the coefficient of friction was observed in the CuSn10/graphite 45 μm composite which contained 0,4 % Ti, with practically no wear of the steel ball (counter-sample). Low coefficients of friction and wear of the friction pair were also reached with other examined composites in CuSn10 matrix. The highest average value of the coefficient of friction and counter-sample weight loss was reached with the CuSn10PTi2/graphite 20 μm composite (1,5 wt. %) which results from the increased content of titanium and phosphorus in the matrix, therefore presence of a hard phase in the composite structure, including titanium carbide, and compounds of Cu - Ti - P and P - Ti systems causing increased wear.

The resulting composite materials are characterized by relatively low wear, as confirmed by SEM microscopic examinations of wear track (Figure 3).

SUMMARY

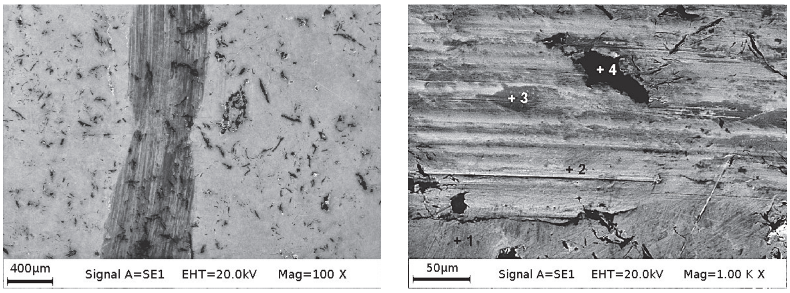
Composite materials were manufactured by melting and casting with mechanical stirring in a liquid state. In order to improve the wettability of graphite particles titanium was added to the metal matrix. In addition, the

a) b) c)

Figure 2 Microstructure of: (a) CuSn10PTi2 composite containing 1,5 wt. % of graphite (20 μm), (b) CuSn10Ti0,4/graphite (45 μm) composite, (c) CuSn10Ti1,5/graphite (45 μm) composite

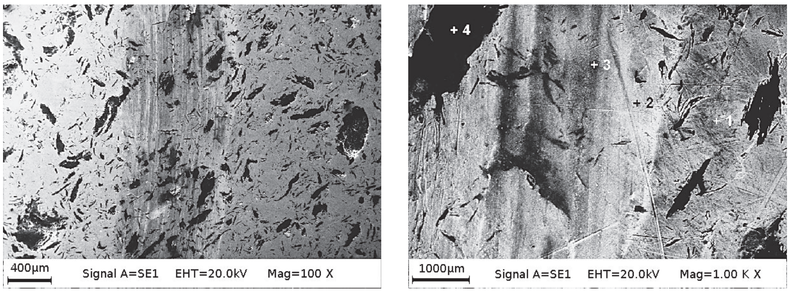
Table 1 **Tribological properties of the investigated composites**

COMPOSITE	Weight loss of a sample / g	Weight loss of a counter-sample / g	Coefficient of friction / μ		Graphite vol. fraction / %
			Mean	Std dev.	
CuSn10P+Ti2/graphite 20 μm	0,0187	0,0010	0,478	0,261	5
CuSn10P+Ti1/graphite 20 μm	0,0009	0,0001	0,151	0,032	10
CuSn10+Ti0,4/graphite 45 μm	0,0001	0,0000	0,048	0,003	10
CuSn10+Ti0,6/graphite 45 μm	0,0016	-0,0001	0,062	0,003	17
CuSn10+Ti1,0/graphite 45 μm	0,0008	-0,0001	0,053	0,002	17
CuSn10+Ti1,5/graphite 45 μm	0,0006	0,0000	0,065	0,003	24



Analysed point	Chemical element / wt. %			
	Cu	Sn	C	O
1	92,38	4,07	3,55	-
2	73,92	19,46	6,12	0,50
3	57,82	5,13	33,33	3,72
4	0,75	-	96,20	3,05

a)



Analysed point	Chemical element / wt. %				
	Cu	Sn	C	O	Fe
1	85,47	7,27	7,26	-	-
2	89,91	2,87	6,45	0,77	-
3	42,97	1,54	48,15	6,76	0,58
4	-	-	96,45	3,55	-

b)

Figure 3 SEM micrographs of the worn surfaces of: (a) CuSn10Ti0,4/graphite (45 µm), (b) CuSn10Ti1,5/graphite (45 µm) composite after interaction with a steel ball

graphite powder particles were heated to about 200 °C before their introduction into the liquid melt.

Qualitative metallographic assessment showed uniformity of microstructure over the entire length of the ingot at relatively low tendency to segregation of all produced composites. The resulting composites are characterized by relatively low coefficient of friction and high wear resistance in dry friction conditions. The composites of the lowest coefficient of friction and wear were characterized by the lowest Ti content in the matrix.

The results indicate possibility of manufacturing of good quality, especially in terms of tribological properties, composite materials with particles of lubricating phase (graphite) in the process of melting and casting with simultaneous mechanical stirring in a liquid state and confirm the possibility of application of the examined composite materials of lead-free copper-graphite type for sliding elements operating in conditions of increased friction and wear.

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Note: The responsible translator for English language is A. Matuga, Katowice, Poland