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MISCH METAL MICRO-ALLOYING EFFECT ON MECHANICAL PROPERTIES OF BABBITT ALLOYS

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Babbitt alloys are one of the oldest antifriction alloys used for bearings and bearings rolls. During the time the micro-alloying for this type of alloys was realized with Cd, Ni, As, Mg and P. For this paper we selected a ternary alloy Sn-Sb-Cu (YSn83) and we investigated the changes induced by the micro alloying with mischmetal in amounts of 0.1, 0.2, 0.5 and 1%. In this purpose, during the alloying process of Babbitt alloys we have added the CuSnMm master alloys, with the different contents of mischmetal. The optical microstructure obtained was investigated, in comparison with the original alloy, and the Brinell hardness and compression strength were evaluated. The results obtained are promising the HB hardness being improved with 28% and compression strength with 23%..

Keywords: antifriction alloys, misch metal, micro-alloying, mechanical properties

1. Introduction

Rare earths elements are unanimously recognized in metallurgy as surfactants because they reduce the surface / interface tension energy at the level of crystals / dendrites in formation. They can also lead to the formation of hard compounds but also have the role of modifiers, where they even out the distribution of hard compounds in the soft matrix of the base alloy. They are intensively used to refine the structure of steels and non-ferrous alloys (Al, Cu, etc.) [1-6]. The antifriction materials that are mainly used in technique are metals and their alloys as: steel and cast iron from the ferrous group, and from the non-ferrous group alloys based on aluminum, copper, lead, tin and zinc. In most cases, these materials, but especially non-ferrous ones, are complex alloys in which a whole series of other elements will be added in different proportions, such as: As, Ba, Bi, Cd, P, Na, Sb, Si, S, Ti, etc [5, 6].

According to its chemical composition, Y-Sn83 is a ternary alloy, in which the alloying elements are antimony and copper. Y-Sn83 is used applied on steel, cast iron or bronze housings, and in the manufacture of the most varied friction

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torques, especially on roller bearings and linings from the internal combustion engines.

This alloy is represented in the ternary diagram shown in Fig. 1 by point Y. The structural principle phases of the alloy are:

- phase α, in eutectic form, consisting of the ternary solid solution of tin with antimony and copper plus the hard phase of Cu_6Sn_5, having a solidification temperature of approximately 230°C - the phase forms the soft matrix of the alloy;

- the β'''-phase, in the form of a hard-defined compound SnSb, which secondarily crystallizes into cubes;

- phase η ', in the form of a compound defined Cu_6Sn_5, which crystallizes primarily in the form of needles or blades, being the hardest constituent of the alloy [1-3].

From structure the point of view, the alloy therefore consists of a softer matrix in the eutectic form, formed by the ternary solid solution (Sn-Cu-Sb) plus Cu_6Sn_5, which incorporates very hard Cu_6Sn_5 needles or blades, resulted from secondary crystallization [3].

The alloy therefore has a structure in which the soft matrix is eutectic with relatively low melting temperature (230°C), which is advantageous for the anti-jamming function of the alloy, where the hard inclusions consist of Cu_6Sn_5 and SnSb phases.

The hard component of the structure, i.e. the hard phase of Cu_6Sn_5, appears in the form of needles and blades, arranged in the shape of a star and with a fairly uniform distribution in the mass of the alloy. The SnSb phase which is in the form of cuboids, i.e. irregular cubes [1], is also uniformly distributed in the structure.

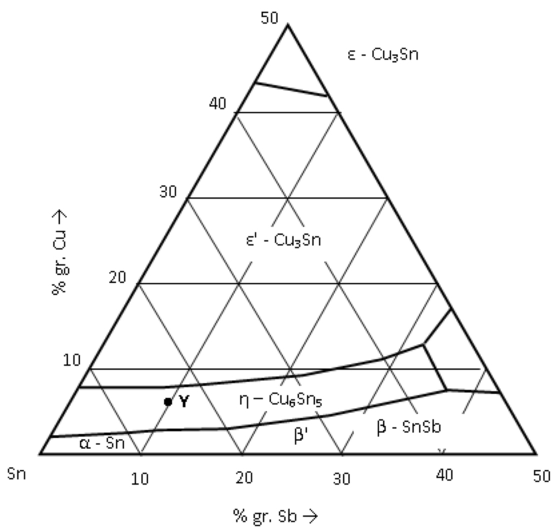

Fig. 1. Ternary diagram of Sn-Sb-Cu system (solid state phases) [3]

The binary eutectic ($\alpha + Cu_6Sn_5$) constitutes the matrix in which the hard phases are embedded. Another important aspect of the alloy structure is the reciprocal position of the SnSb and Cu_6Sn_5 phases appearing interpenetrations of these phases, Cu_6Sn_5 particles being completely included or in the form of SnSb cuboids inlets. [4]

In various forms, the alloying elements will bring properties on the final alloy which are directly related to the lubrication process or contribute to the improvement of metallurgical conditions and their mechanical processing [1-6].In terms of wear, the structure constituents are recommended to be tough, because in this case the abrasive wear will be reduced. The overall hardness of the material is also influenced by the presence of hard phases in the structure [1, 7]. These hard and fragile constituents have a support role for the shaft, and the soft and plastic metal mass, contributes to the reduction of the friction coefficient, ensuring at the same that the complex solicitations transmitted by the moving shaft to the hard crystals are taken over [8-10].

For this study, a novel approach for mischmetal micro-alloying was investigated, where 0.1, 0.2, 0.5 and 1% Mm was added to the composition, in order to obtain a better performance.

2. Materials and Methods

The starting point is to produce the Y-Sn83 alloy. The crucible will be preheated at a temperature of 500-550°C.

The Cu-Sb master alloy is loaded, then the Sb and part of the Sn (approximately 20-35% from the total amount of Sn contained in the load). The load is covered with a layer of dry coal.

After load melts, the temperature of the alloy will rise to 600-700°C. Then the slag and the coal layer from the metal surface will be removed and the rest of the tin will be introduced the mixture, in several portions, while continuously mixing the liquid alloy with a steel spoon. The alloy is kept for 10-15 minutes at 550-600°C, after mixing. Then after homogenizing the melt, the slag is removed at a temperature of 425-450°C and it will be poured into a metal shell.

For microalloying the Babbit alloy obtained in the sequence prior presented an additional step was considered. We developed the material as described and we introduced the rest of the tin into the metallic bath, it will be mixed and maintained for 10-15 minutes at 550-600°C. The master alloy CuSnMm is added, mixed for 1-2 minutes, the slag is removed at a temperature of 425-450°C and it is poured into a metal shell.

After introducing the master alloy with Mm in the metallic bath, for the additional protection of the molten metal bath, a stream of Ar was blown into the oven, which was dried and purified by a CRS purifying cartridge. Ar flow rate: 1-1.5 l / min. Chemical composition of the starting alloy is shown in table 1.

Table 1

Chemical composition of antifriction alloys Y-Sn83

Alloy Commercial Name	Chemical composition % wt							
	Sn	Sb	Cu	Pb	Al	Mg	-	Other elements
Y-Sn83	bal	11.32	5.74	0.05	-	-	-	-
	Ce	La	Nd	Pr	Sm	Yt	Fe, Si, P	Other elements
Mm	bal	24.5	11.4	5.6	1.8	1.5	1.4	<0.1

Chemical composition for the alloy produced for these experiments was realized by inductive plasma emission spectroscopy (ICP-OES Spectroflame P, Germany) for Sn, Sb, Cu and Pb and with optical emission spectroscopy with continuum current plasma (DCPSpectraspan V Beckman, Germany) for rare earth elements.

The metallographic analysis of the alloy samples was performed with a metallographic microscope, with polarized light, of AxioImager A1m - Carl Zeiss type.5.6

The microscopic images were obtained by using a Canon Power Shot A 640 digital camera, 10X digital zoom, and processed with specialized PC software AxioVision Release 4.6.3.

The orders of magnifications were x200 and x900.

For the study, the samples were embedded in bakelite-type resin, and then prepared by grinding with abrasive paper and polishing with Lecloth-type cloth soaked with a suspension of α-alumina in water. Nital 5% solution was used for the attack.

Dynamic compressive deformation resistance of the YSn83 alloy was determined by the repression method. The principle of the method [9-12]: The compression test, or the discharge test, involves the use of cylindrical specimens with the help of which both cold and hot plastic properties of metal materials can be determined. Because the state of effort that occurs in real conditions (plastic deformation or technological use), the compression test makes it possible to determine the data necessary for the practice and especially the resistance to deformation.

The compression test evaluates the “relative plasticity” due to the fact that in the test piece subjected to the discharge, the appeared tensions and deformations are inhomogeneous [13].

The method consists in measuring the deformation of specimens after being hit with a hammer (ram) with the weight M falling from a height H.

The calculation formula of the deformation resistance (R_d) was determined starting from the relation of the mechanical deformation work (L):

$$L = R_d\left(1+\frac{\mu \cdot d_1}{3 \cdot h_1}\right)\cdot V \cdot \varepsilon_u \quad , [\text{ J }] \tag{1}$$

where:
μ = 0.2 – 0.4 is the external coefficient of friction;
d_1, h_1 – mean diameter and height of the specimen after deformation, mm;

$$d_1 = d_0\sqrt{\frac{h_0}{h_1}} \tag{2}$$

d_0, h_0 – diameter and height of the specimen before deformation, mm;
V – the volume of material subjected to deformation;
ε_u – the degree of deformation achieved at a stroke unit

$$\varepsilon_u = (h_0 - h_1)/h_0 \tag{3}$$

Replacing the mechanical work L from the formula with the striking energy E = G·H·η result:

$$R_d = \frac{G \cdot H \cdot \eta}{\left(1+\frac{\mu}{3}\cdot\frac{d_1}{h_1}\right)\cdot V \cdot \varepsilon_u} \quad , [\text{ MPa }] \tag{4}$$

where: G = 329.28, N being the weight of the sonnet ram (m=33.6 kg);
H = fall height;
η = 0.9 – yield.

The determination of the Brinell hardness of the developed antifriction alloys was performed using a WPM hardness tester model HPO 3000, Germany. Principle of the method as presented in Fig. 2:

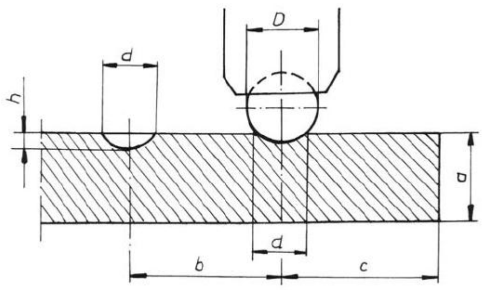

Fig. 2. Schematic of the Brinell hardness test method

The hardness measurement by the Brinell method, standardized by STAS 165, consists in printing a given time, with a force F of a hardened steel or tungsten carbide ball, with the prescribed diameter D, perpendicular to the surface of the test piece and measuring the diameter d.

Brinell hardness is expressed as a conventional quantity, by the numerical value given by the formula:

$$HB = \frac{2F}{\pi \cdot D\left(D - \sqrt{D^2 - d^2}\right)}, [daN / mm^2] \quad (5)$$

where F is the force applied to the penetrator, measured in N

Basically, this calculation is not necessary because there are tables that show the value of HB hardness according to the values of *F*, *D* and *d* (STAS 155 – 83). The measurements were performed under the following conditions:

Table 2

Measurement conditions

Pressing force [daN]	D [mm]	Holding time [s]	Temperature [ºC]
250	10	60	20, 50±1, 100±2

3. Results and Discussions

The composition of the alloy after microalloying is presented in Table 3.

Table 3

Chemical analysis of Y-Sn83 alloy samples [% gr.]

Sample	Alloying element [%wt]	Sn	Cu	Sb	Pb	Zn	Fe	Al	Mm	Other*
YSM 1	0.1	bal	6.03	11.34	0.02	<0.01	0.01	<0.01	0.09	<0.01
YSM 2	0.2	bal	5.97	11.68	0.01	<0.01	0.01	<0.01	0.18	<0.01
YSM 3	0.5	bal	5.88	11.08	0.01	<0.01	0.01	<0.01	0.48	0.02
YSM 4	1.0	bal	5.96	10.85	0.02	<0.01	0.02	<0.01	0.93	0.02

***) Other: Bi, Na, Si, P (from Mm)**

The results confirmed the composition we designed and we obtained after melting, alloying and casting process.

The macrostructure of the ingot produced for analyses and further testing is presented in Fig. 3.

Fig 3. Ingots of Babbit alloys prepared for testing.

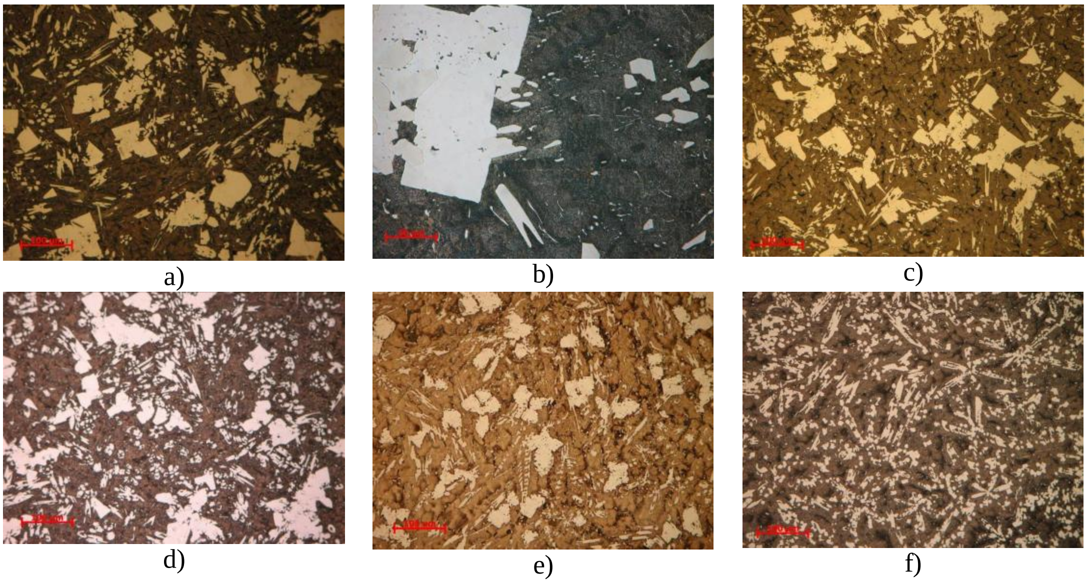

Fig 4. Microstructure of the alloys produced: a) YSn83 cast alloy, b) YSn83 cast alloy (x900), c) YSn83 with 0.1% Mm e, d) YSn83 with 0.2% Mm, e) YSn83 with 0.5% Mm, f) YSn83 with 1.0 % Mm; (a, c, d, e, f x200 magnification)

Fig. 4 a) reveals the structure consisting of acicular compounds of Cu_6Sn_5 and SnSb cubes embedded in a ternary eutectic mass consisting of α solid solution, Sn(Sb) and Cu4Sn intermetallic compound. In Fig. 4 b) the Cu_6Sn_5 phase with SnSb cuboids is observed. Adding 0.1%Mm does not modify dramatically the microstructure. The lamellas of Cu_6Sn_5 are observed together with SnSb cubes as it can be seen in Fig. 4 c). Increasing the Mm amount to 0.5% will reduce the occurrence of SnSb cubes and the solid solution is enriched with acicular compounds of Cu_6Sn_5 (fig. 4 d)). The amount of 1%Mm reduced almost completely the SnSb cubes and the occurrence of Cu_6Sn_5 is more abundant and uniformly distributed in the soft matrix of the alloy.

The values of the hardness measurements obtained are presented in Table 4.

Table 4

HB Hardness measurements 250/10/60

Sample	20 °C				50 °C	100 °C
	Test 1	Test 2	Test 3	Mean HB		
YS - YSn83	28.8	28.3	27.6	28.23	**21.7**	**11.5**
YSM 1	28.5	29.1	28.7	28.37	**21.9**	**11.7**
YSM 2	28.7	28.9	29.2	28.83	**22.2**	**11.1**
YSM 3	29.5	28.9	29.3	29.85	**21.3**	**11.5**
YSM 4	30.2	29.7	29.7	29.88	**22.1**	**11.8**

In Fig. 5 is presented the diagram with the variation of the hardness of the anti-friction alloys depending on the content of the micro-alloy element.

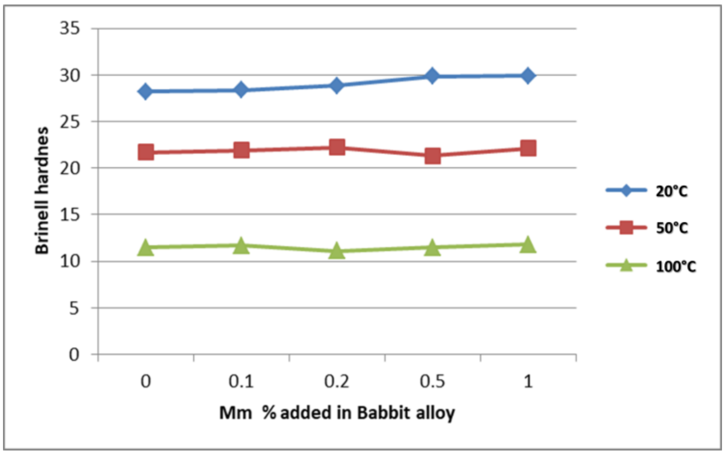

Fig. 5. The hardness of Y-Sn83 microalloyed

In Fig. 5 we can observe that at room temperature the Brinell hardness of the Babbit alloy is the lowest and when adding Mm the hardness increases significantly. At 50°C the behavior of the Brinell hardness is changed and the value is lower for all the alloys investigated. Also the Babbit alloy with 0.5%Mm has the lowest value for the hardness but the difference between microalloyed samples is minor. At 100°C the lowest Brinell hardness values goes to the Babbit alloy microalloyed with 0.2%Mm. So raising the temperature decrease the Brinell hardness and the variation is dependent on the amount of Mm added. The alloys should be designed according to their purpose and the amount of Mm chosen in accordance with this purpose.

Table 5

Discharge test results of specimens

Sample	The fall energy of the ram	Unitary degree of deformation ε_u	Deformation resistance (compression) R_d	Sample appearance
	[J]		[daN/mm^2]	
YS -	296352	0.163	17.747	"Barrel" shape, no

YSn83				cracks or visible defects
YSM 1		0.160	18.08	-- , --
YSM 2		0.159	18.25	-- , --
YSM 3		0.159	18.21	-- , --
YSM 4		0.155	18.68	-- , --

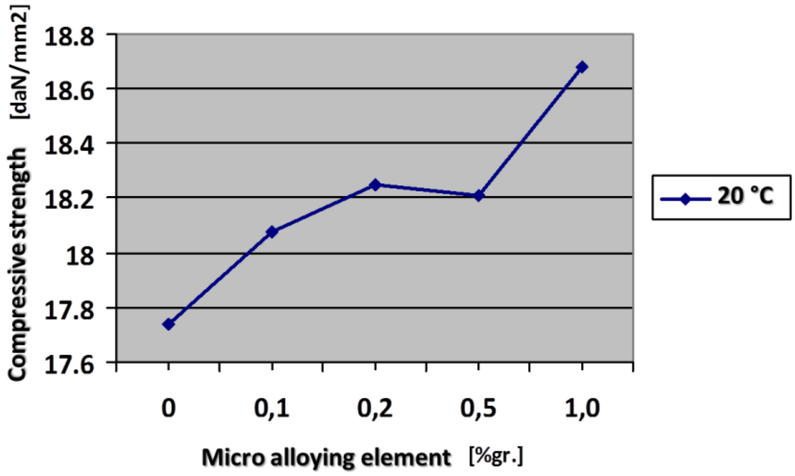

Fig.6. Compression strength of Y-Sn83 microalloyed

The compression value for the 0.5%Mm is lower than the one for 0.2%Mm and also the hardness at 100°C is lower. The microstructure as presented in Fig. 5 d) and e) are not very different so the results suggest that the use of 0.2%Mm is better to be used instead of 0.5%Mm. One of the novelty of this study is adding 0.2%Mm in the composition because usually the 0.5% is preferred as can be observed in Fig. 6. The best results obtained in all the cases were for 1%Mm.

4. Conclusions

Quantitative chemical analysis of developed alloy batches showed that they correspond - within the limits of accuracy given by the methods of analysis - the desired nominal compositions;

The use of mischmetal in the form of master-alloys, and the adoption of measures to protect the metal bath (coal layer, respectively blowing of inert gas - Ar in the furnace) reduced the losses of mischmetal; the contents of the mischmetal (sum of elements) in the alloys being close to the values laid down in the load calculation;

Compared to the microstructure of standard alloys, without the addition of microalloy elements, modified alloys / microalloys with Mm have a modified structure in the sense of reducing the dimensions of some phases until their disappearance;

Thereby in the case of the Y-Sn83 alloy, with the increase of the Mm content, the size of the cubic phase SnSb is reduced until the total disappearance at a Mm content of 1.0%.

The test performed on the samples revealed that the best results were obtained for Babbit alloy microalloyed with 1%Mm and the 0.2%Mm presented better results than 0.5%Mm.

The mechanical properties of the Babbitt alloy microalloyed with different amounts of Mm were influenced by temperature and the Mm content so the alloy should be designed according to the usage in the future application.

R E F E R E N C E S

[1]. *T.E. Abioyea, H. Zuhailawatib, M.A.I. Azlanb, A.S. Anasyidab,* Effects of SiC additions on the microstructure, compressive strength and wear resistance of Sn-Sb-Cu bearing alloy formed via powder metallurgy, Journal of Materials Research and Technology, **vol. 9**, Issue 6, Nov. 2020, pp. 13196-13205

[2]. *Y. Ijiri, P. K. Liaw, B. J. Taszarek, S. Frohlich, and M. N. Gungor*, Correlation of mechanical properties with non-destructive evaluation of babbit metal/bronze composite interface, Metallurgical transactions A, **vol. 19A**, Sep. 1988, pp. 2215–2224

[3]. *B.S. Ünlüa, E. Atik,* Evaluation of effect of alloy elements in copper based CuSn10 and CuZn30 bearings on tribological and mechanical properties, Journal of Alloys and Compounds, **vol. 489**, Issue 1, Jan. 2010, pp. 262-268

[4]. *K.H. Matucha*, Structure and Properties of Nonferrous Alloys, ISBN: 3-527-26821-9, WILEY-VCH Verlag GmbH, D-69469, 1996, Weinheim, Germania

[5]. *T. Mang, K. Bobzin, T. Bartels*, Industrial Tribology. Tribosystems, Friction, Wear and Surface Engineering, Lubrication, WILEY-VCH Verlag & Co. KGaA, Germania, 2011.

[6]. *F. Niculescu, I. Constantin, M. Buzatu, D.F. Marcu, I. Csaki,* The thermodynamic Properties Of The Pb-Sb System, University Politehnica Of Bucharest Scientific Bulletin Series B-Chemistry And Materials Science, **vol. 78**, Issue: 4, 2016, pp. 215-224

[7]. *Gh. Manea*, Organe de mașini, **vol. 1**, Ed.Tehnică, București, Capitolul Lagăre cu alunecare, 1970, pp. 735-347

[8]. *S. Guruswamy*, Engineering properties and applications of lead alloys, Marcel Dekker Inc., NY SUA, 2000.

[9]. *W.A. Glaeser*, Materials for tribology, Elsevier Science Phblishers B.V. Amsterdam, Olanda, 1992.

[10]. *F. Habashi* (Editor), Alloys - Preparation, Properties, Applications, ISBN 3-527-29591-7, WILEY-VCH Verlag GmbH, D-69469 Weinheim, Germany, 1998.

[11]. *K.C. Ludema*, Friction, Wear, Lubrication, A Textbook in tribology, CRC Press LLC, SUA, Chapter 7: Metallic antifriction materials, 1996, pp. 223-254

[12]. *M. Ramadan, A. S. Alghamdi, T. Subhani and K. S. Abdel Hali*, Fabrication and Characterization of Sn-Based Babbitt Alloy Nanocomposite Reinforced with Al2O3 Nanoparticles/Carbon Steel Bimetallic Material, *Materials* **2020**, *13*(12), 2759

[13]. *K.H. Matucha*, Structure and Properties of Nonferrous Alloys, ISBN: 3-527-26821-9, WILEY-VCH Verlag GmbH, D-69469 Weinheim, Germany, 1996.