SLIDING WEAR BEHAVIOR OF Zn-Al ALLOYS IN CONDITIONS OF BOUNDARY LUBRICATION

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ABSTRACT

In the paper are presented experimental results of tribological investigations made to study tribological behaviour of RAR Zn-Al alloys in conditions of boundary lubrication. In order to clearly establish the tribological potential of these alloys as bearing materials, the tribological parameters of the RAR Zn-Al alloys are compared to parameters of the CuPb15Sn8 lead-tin bronze, as a widely applied conventional bearing material.

The established level of tribological characteristics, both from aspect of wear and aspect of friction, show that RAR Zn-Al alloys represent respectable tribological materials, convenient for bronze substitution.

KEYWORDS: Zn-Al alloys, bronze, tribology, friction, wear, bearing.

1. INTRODUCTION

Though conventional bearing materials (especially bronzes) are still dominating in industrial practice, in the past two decades there is a growing number of published information about results of investigation on their substitution by zinc-aluminium alloys [1, 2, 3, 4, 5].

The basic motive of such an investigations is of course, of economic nature. Namely, the Zn-Al alloys are characterized by significantly lower price. Besides that, these alloys can successfully be machined by standard casting procedures, like sand casting, centrifugal, permanent and continual casting. Total savings of substitution bronzes with these alloys are estimated up to the level of 35…90% [3].

The concept of application of Zn-Al journal bearings as substitution for the bronze ones is not new [2]. The first experiences are related to the period of the Second World War, when different Zn-Al alloys (before, all with only 30 % Al) were used instead of bronze, primarily due to lack of copper. Besides bearings, the Zn-Al alloys were applied also for other machine elements, like the worm gears, components of hydraulic installations etc.

Special importance in development of Zn-Al alloys during the seventies and eighties has the International Lead and Zinc Research Organization. Based on their investigations and those of other research centers and manufacturers in this area, the Zn-Al alloys for casting were developed, marked as ZA-8, ZA-12 and ZA-27. Such coding (in which the numerical code denotes the content of aluminium) is accepted also by the ASTM standards B 669-89, while according to European norm EN 1774-98 the following codes are used: ZL8, ZL12 and ZL27.

Based on positive world experiences in the area of the ZnAlCuMn alloys, and also based on our own investigation, company RAR from Belgrade, using exclusively domestic raw materials, starts casting these alloys, primarily those with aluminium content over 10 %, like RAR-12 and RAR-27.

Realized good carrying capacity and wear resistance enabled application of these alloys, especially for mining equipment and mechanization for tribo-elements, like the sliding radial and journal bearings, various bushings, nuts for the screwed spindles, guides, etc.

Systematic investigations of the RAR alloys characteristics, with aim to evaluate them as the tribological material for manufacturing the sliding elements, were supported by the Ministry for Science and Technology of Republic of Serbia, as well as a series of customers, within the two innovation projects [6, 7, 8, 9].

In this paper there are just presented some of the obtained results showing the possibility of substitution of bronzes, what, besides other, is very significant from the aspect of reducing the needs for importing the deficient tin.

2. EXPERIMENTAL PROCEDURE

2.1. Tested Materials

For the tests there were prepared two types of RAR Zn-Al alloys with commercial marks RAR-12 and RAR-27, cast in ingot mold. RAR-12 and RAR-27 alloys are in accordance with ZA-12 and ZA-27 alloys defined by ASTM B 669-89. In order to provide a comparative evaluation of RAR alloys, lead-tin bronze CuPb15Sn8 was used. Chemical compositions and physical-mechanical properties of these materials are given in tables 1 to 3.

Table 1. Chemical composition of RAR alloys.

Chemical elements, %	RAR-27	RAR-12
Al	26.20	14.4
Cu	2.30	1.3
Mg	0.02	0.018
Zn	Remaining	Remaining

Table 2. Chemical composition of CuPb15Sn8.

Chemical element	Percentage content
Cu	76.0
Sn	7.63
Pb	12.31
Others	Remaining

Table 3. Physical-mechanical properties of alloys.

Physical-mechanical properties	Tested materials		
	RAR-27	RAR-12	CuPb15Sn8
Hardness, HB	115	94	90
Tensile strength, MPa	451	305	188.9
Extension, %	16.7	10.2	7.85
Yield strength $R_{p0.2}$, MPa	353	210	131.7
Elasticity modulus, GPa	137.6	1	110
Density, kg/dm^3	5.0	6.1	8.28

2.2. Wear Test Equipment

Tribometric tests were performed on the computer-supported tribometer (fig. 1). Computer support for the experiment was enabled by application of the Burr-Brown PCI 20000 data acquisition system integrated into PC computer and general-purpose *LABTECH NOTEBOOK* software package.

Based on requirements to realize the contact and relative motion type similarity on model and real system, for tribological modelling of sliding bearing was chosen (in tribometric practice, the most present) pin-on-disc contact scheme with continuous sliding.

As in real tribological system bearing/journal, the tribologically critical contact element is the bearing, on the model, the stationary pin corresponds to it, which is due to a small degree of covering tribologically more critical contact element of the contact pair on the model.

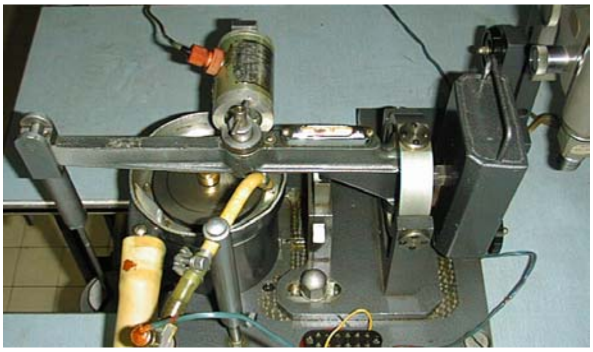

Fig. 1. Pin-on-disc testing device.

In conducted tests pins of cylindrical form were used, with diameter of 2.5 mm, with flat, ground front (contact) surface (nominal contact area 5 mm^2), and made of tested bearings materials. Rotational discs of diameter 100 mm were made of construction Chromium-Nickel-Molybdenum steel C 4732 which was thermally treated, having a hardness of 38 HRC. Contact surfaces were machined by grinding, under the same conditions. The machined contact surfaces quality of pins and discs is characterized by roughness at the level of approximately R_a = 0.3 μm.

The selected wear specimens were tested in conditions of 0.15 m/s sliding speed, 3, 5 and 7 MPa contact pressure, respectively. These parameters provide "p·v" characteristics of 450, 750 and 1050 [kN/m^2 (m/s)], that correspond to the typical values of journal bearing applications with boundary lubrication.

The tests were performed in conditions of room temperature. The lubricant used for tests was ISO grade 68 hydraulic oil, a multipurpose lubricant recommended for industrial use in plain and antifriction bearings, electric motor bearings, machine tools, chains and gear boxes, as well as high-pressure hydraulic systems. The oil was heated up to 50 °C.

Individual tribometric tests for each of combinations of the contact conditions were conducted for 4.5 hours, what corresponds to the friction distance of 3000 m.

3. RESULTS AND DISCUSSIONS

By periodical measurement of mass loss of pins, using an analytical balance capable of accuracy measuring of 0.001 g, and continuous measurement of the friction parameters, the series of data were generated, by whose processing the results were obtained that may by used for RAR alloys evaluation in condition of boundary lubrication.

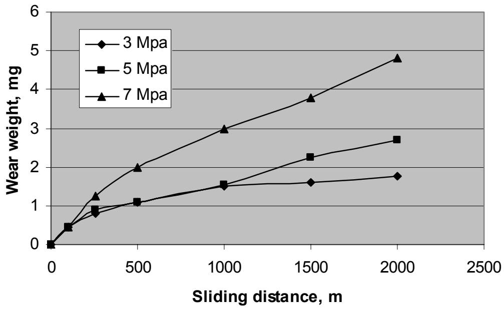

Fig. 2. Wear curves of RAR-27 alloy.

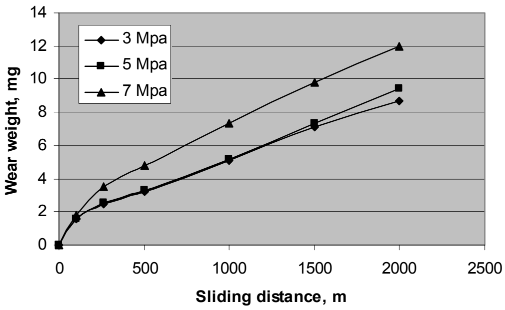

Fig. 3. Wear curves of RAR-12 alloy

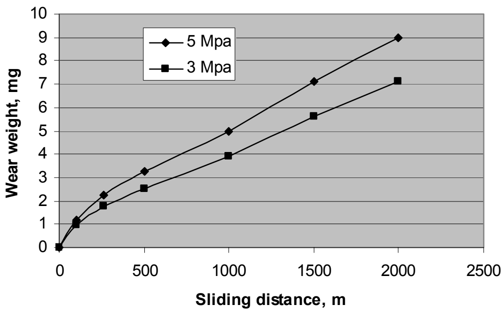

Fig. 4. Wear curves of CuPb15Sn8 bronze.

The graphical representation of the wear results obtained from the tests for RAR-12, RAR-27 and lead-tin bronze CuPb15Sn8 are shown in figures 2, 3 and 4. The data used for graphs were taken from the average of five measurements. The standard deviation was below 5%. These wear curves represent the functions of the wear mass loss versus the friction distance for the varied levels of pressure. Results of wear tests of CuPb15Sn8 samples obtained by 7 MPa of pressure were not accepted as significant, because of a great dissipation of values. It is obvious that the curves of all tested alloys, under the applied loads, have the classical form with the expressed running-in period and period of a steady state wear behavior.

Based on the wear curves, the corresponding rates of wear were calculated, in two ways, as the wear mass rate in *mg/h* and as the wear volume rate in mm^3/h (table 4). In the given table are presented the total wear rates. The volume wear rate is used due to different density of the tested materials.

For a comparison of the tested alloys the volume wear rate was chosen, since it is directly related to linear wear, which is, in the system of journal bearing, responsible for the increase of clearance and loss of the bearing's working ability (figures 5, 6 and 7).

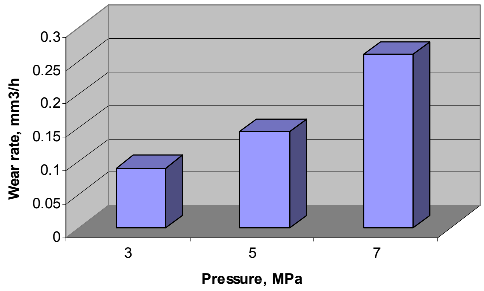

Fig. 5. Wear rate of RAR-27 vs. applied pressure.

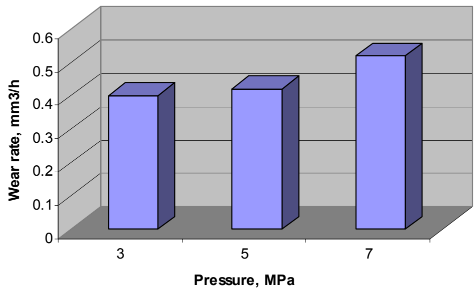

Fig. 6. Wear rate of RAR-12 vs. applied pressure.

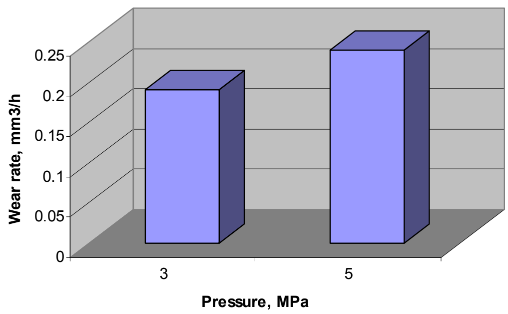

Fig. 7. Wear rate of CuPb15Sn8 bronze vs. applied pressure.

Table 4. The wear rates of RAR alloys.

Pressure, MPa	RAR-27			RAR-12			CuPb15Sn8		
	mg/h	mm^3/h	*Friction coefficient*	*mg/h*	mm^3/h	*Friction coefficient*	*mg/h*	mm^3/h	*Friction coefficient*
3	0.46	0.09	0.108	2.40	0.40	0.118	1.73	0.19	0.115
5	0.72	0.144	0.1	2.54	0.42	0.119	2.20	0.24	0.105
7	1.31	0.26	0.089	3.13	0.52	0.104	-	-	

It can be found clearly from the graph that the wear rates of the tested alloys increase with the increase in applied load, what was expected in conditions of the boundary lubrication. In accordance with the wear curves and charts of wear rates for RAR alloys the degree of wear increasing that corresponds to pressure increasing from 3 to 5 MPA is almost insignificant, especially in a running-in period and beginning of steady state period of wear. Also, it is clear that RAR-12 alloy shows more moderate wear sensitivity to contact pressure change. In the case of CuPb15Sn8 bronze influence of pressure increasing on wear rate is significant. For all the three levels of contact pressure RAR-27 has the lowest wear rates.

During the friction process There were continuously measured the normal force F_N, the friction force F_T and temperature T. Data were gathered with 10 Hz sampling rate, forming the numerical channel with calculated values of the friction coefficient. The example of the friction force output signal is given in figure 8.

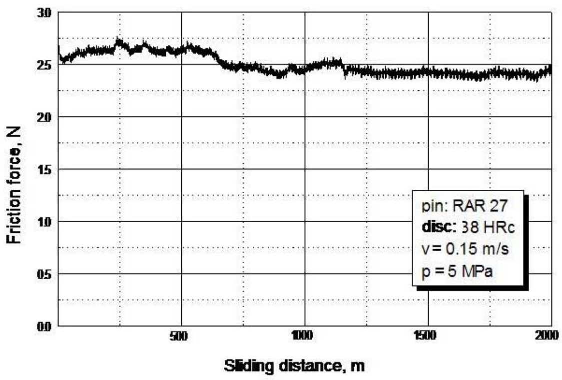

Fig. 8. Example of friction force data during sliding.

The graphical representation of the friction coefficient results obtained from the tests is shown in figures 9, 10 and 11. The values on diagrams represent the average values based on 5 completely repeated tests for each combination of contact materials and loads. Thus, the value of the friction coefficient of one test is the average value of the whole-considered sliding duration.

The established decrease of the friction coefficient with increase of the contact pressure, in three tested bearings materials, is in compliance with known principles of the frictional behaviour of the metallic materials in the boundary friction conditions.

Thus, the tendency of the friction coefficient decreases with increasing pressure, is significantly more prominent for the RAR-27 and CuPb15Sn8 bronze. For all the three levels of contact pressure RAR-27 has the lowest friction coefficients.

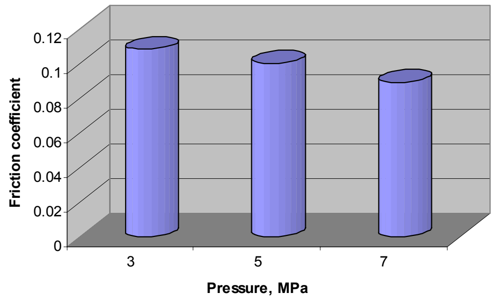

Fig. 9. Friction coefficient of RAR-27 vs. applied pressure.

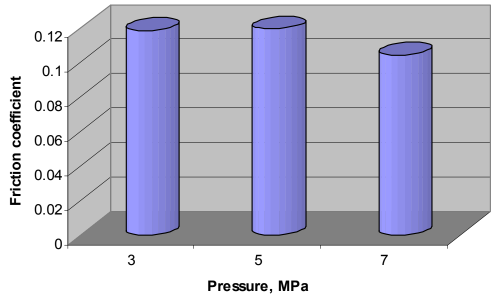

Fig. 10. Friction coefficient of RAR-12 vs. applied pressure.

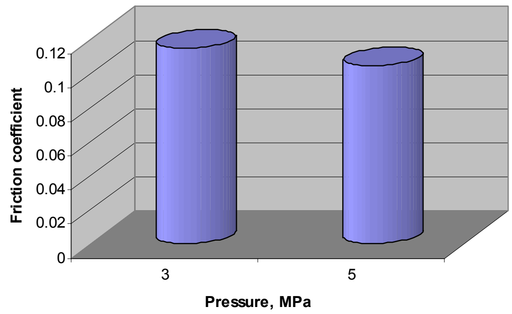

Fig. 11. Friction coefficient of CuPb15Sn8 bronze vs. applied pressure.

Due to the possibility of direct comparison of tribological properties of materials, which are obtained in different contact conditions, it is usual to use the parameter which represents the wear per the unit of the normal contact load and the sliding distance. This parameter is known as the specific wear rate or wear intensity. Values of this parameter for the compared alloys are given in table 5, where is for comparison, also for this case, used the volume wear.

Table 5. Wear resistance of tested alloys.

Alloys	RAR-27		RAR-12		CuPb15Sn8	
Pressure, MPa	Wear resistance X 10^{-6}, mm^3/Nm	Friction coefficient	Wear resistance x 10^{-6}, mm^3/Nm	Friction coefficient	Wear resistance x 10^{-6}, mm^3/Nm	Friction coefficient
3	11	0.108	49.33	0.118	20.9	0.115
5	10.6	0.1	31.08	0.119	17.7	0.105
Average	10.8	0.104	40.205	0.1185	19.3	0.11

Taking in consideration that the chosen contact pressures mainly cover the whole range of real sliding bearings loads, a general comparison of the tested alloys tribological behaviour can be done based on the average values of wear resistance and friction coefficient.

The corresponding graphic representations of wear resistances and friction coefficients of tested materials based on average values are shown in figures 12 and 13.

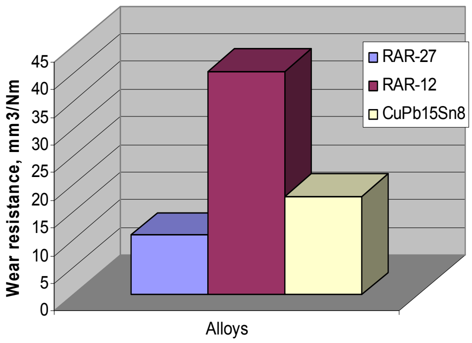

Fig. 12. Average wear resistances of tested alloys.

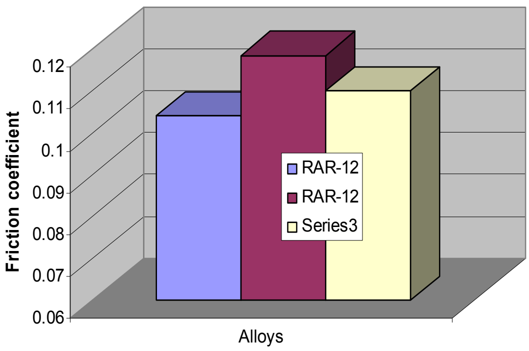

Fig. 13. Average friction coefficients of tested alloys.

Established levels of tribological characteristics, from the aspect of wear resistance, as well as friction coefficient, confirm that both commercial RAR Zn-Al alloys (RAR-12 and RAR-27) represent respectable tribological materials for conditions of boundary lubrication, that are characteristic for high loads and low sliding speeds.

Obtained results show that chemical composition varying from RAR-12 to RAR-27 provides very significant improvement of friction and wear characteristics. In accordance with that, RAR alloys can be used in a broad range of contact conditions.

The main question is related to the substitution of traditional bronze possibility. Obtained results point out that, under the same testing conditions, for all applied loads, lower wear rate, for the given friction distance, corresponds to material RAR-27 with respect to material CuPb15Sn8. It can be seen that the larger differences in the wear rates correspond to lower contact loads.

Besides proeminent advantage with respect to the wear characteristics, another advantage can be noticed also, that one being related to the anti-frictional characteristics of the RAR-27 alloy, with respect to the lead-tin bronze, what was illustrated by figure 13.

4. CONCLUSIONS

The established level of tribological characteristics, both from aspect of wear and aspect of friction, shows that RAR Zn-Al alloys represent respectable tribological materials.

Considering the simulated conditions of tribological interactions, the results nominated these alloys as candidates for bearing's materials for conditions of boundary lubrication, that are characteristic for high loads and low sliding speeds.

With respect to bronze they have better anti-frictional characteristics, higher resistance to wear and lower price costs.

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