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THE INFLUENCE OF STRONTIUM ADDITION ON THE TRIBOLOGICAL PROPERTIES OF Zn25Al1Si ALLOY IN BOUNDARY LUBRICATED CONDITION

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Abstract: *The zinc-aluminium based casting alloy ZA-27 is well-established alloy and is frequently used materials for sleeves of plain bearings. It has good physical, mechanical and tribological properties. However, one of the major disadvantages is its dimensional instability over a period of time (ageing). To overcome this, the copper in the alloy may be replaced by silicon. Coarsening of the silicon particles is controlled by suitable additions of strontium. The influence of the strontium addition on friction and wear properties in boundary lubricated conditions was done on block-on-disc tribometer. The tests were carried-out for three Zn25Al1Si alloys with variable strontium content (0 wt. %, 0.03 wt. % and 0.05 wt. %), and, for the purpose of comparison, for standard ZA-27 alloy. Tests have confirmed that the wear rate of zinc-aluminium alloys with silicon is lower than the standard ZA-27, and have shown that the strontium addition lowers that rate additionally, with the slight increase of the coefficient of friction.*

Key Words: *Zn-Al alloys, strontium addition, sliding, boundary lubrication, friction, wear*

1. INTRODUCTION

The zinc-aluminium based casting alloy ZA-27 is well-established alloy and has widely been used in a variety of tribological applications as cost and energy effective substitutes to bronzes, cast irons and aluminium alloys [1,2]. It major disadvantages, like all conventional zinc-aluminium alloys containing 8 to 28 wt. % Al and 0.5 to 2.5 wt. % Cu, are inferior mechanical properties at temperatures above 100 °C [1,3] or 120 °C [2,4] and long-term dimensional instability (irreversible change of dimensions over a period of time) [1,2,5]. Heat treatment of the conventional zinc-aluminium alloys reduces the extent of dimensional changes but also deteriorates their hardness and tensile strength while ductility and sliding wear behaviour improve after the treatment [1,6].

Another approach, to overcome dimensional instability, is to replace the copper with silicon. The silicon not only improves the dimensional stability of zinc-aluminium alloys but also the wear properties [2,3,6]. However, too high silicon content can deteriorate the wear characteristics, and for each Al content there exists an optimum Si content [7]. This appears to be due to a coarsening of the silicon particles. Modification of the alloy melt with strontium addition prior to solidification refines the silicon structure, and improves the wear resistance [8].

The idea of this paper was to investigate the influence of strontium addition on the tribological properties of Zn25Al1Si alloy, since its addition already improved alloy structure. The tests were carried-out for three Zn25Al1Si alloys with variable strontium content (0, 0.03 and 0.05 wt. %), and, for the purpose of comparison, for standard ZA-27 alloy.

2. EXPERIMENTAL DETAILS

2.1. Materials

The investigated materials were made in the Department of Materials Science of the “Vinca” institute. The chemical composition of the alloys is given in Table 1. Technically pure zinc and aluminium were used to obtain these alloys, with the addition of master alloys Al7Si and Al18Si for achieving the desired content of silicon. Strontium was added in the alloys using the master alloy Al10Sr. The alloys were melted in the laboratory electric resistance furnace. The molten alloys (570 °C) were poured in the steel moulds preheated to 200 °C. Immediately before pouring the melts were intensively mixed by hand. In addition, for the purpose of comparison, a commercial ZA-27 alloy [9] was used (designated as ZA-27). The alloy was supplied from the RAR® foundry, Batajnica.

The alloy was also casted following the procedure identical to that for Zn-Al-Si and Zn-Al-Si-Sr alloys.

Table 1. Chemical composition of Zn-Al-Si and Zn-Al-Si-Sr alloys (wt. %)

Alloy designation	Al	Si	Sr	Zn
Zn25Al1Si	25	1	0	Balance
Zn25Al1Si-0.03Sr			0.03	
Zn25Al1Si-0.05Sr			0.05	

The microstructures of the tested materials were examined on the samples prepared in the standard metallurgical way and etched with 9 vol. % water solution of HNO_3 (Fig. 1). The microstructure of the conventional ZA-27 alloy (Fig. 1a) consists of complex dendrites with the core (α phase), the periphery (a mixture of α and η phase) and the interdendritic space (η phase). The elements of the structure are indicated in Fig. 1a. The α phase is rich in aluminium and the η phase contain about 93 wt. % zinc [10]. The morphology of the dendrites is a consequence of the peritectic reactions during the solidification of the alloy [11].

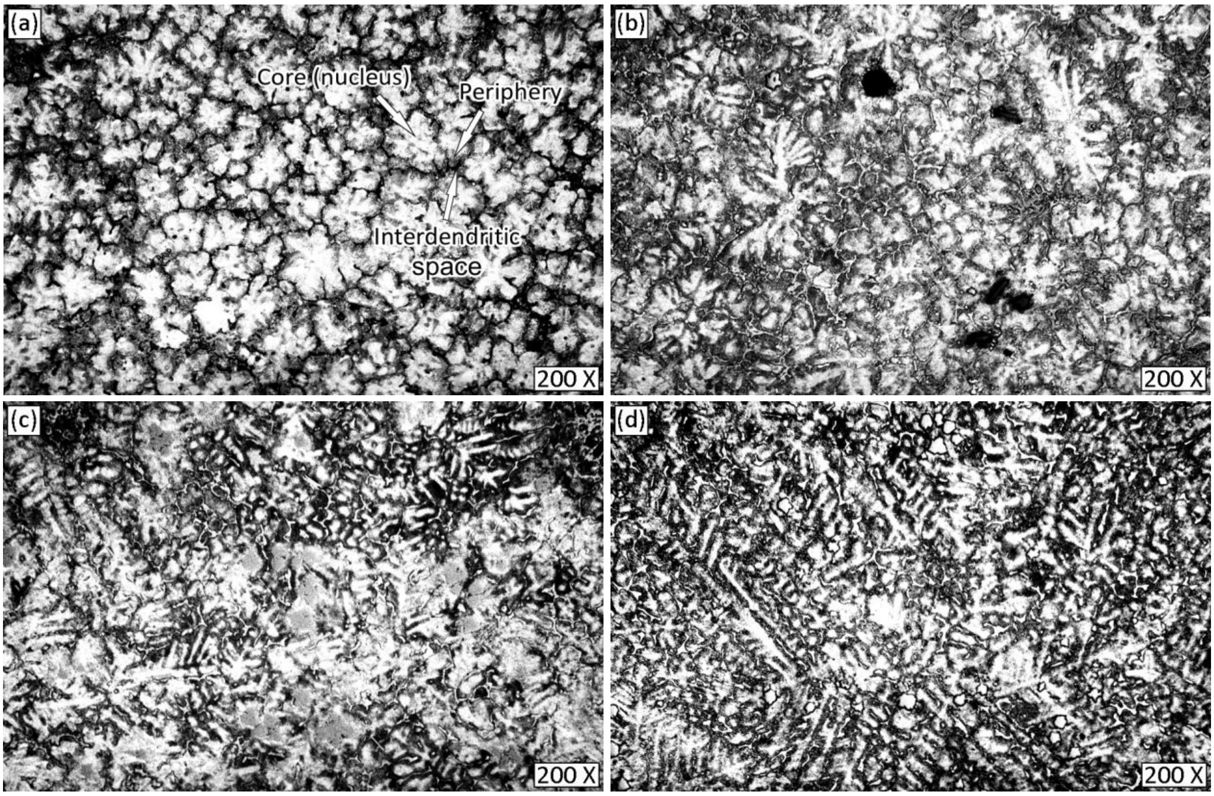

Fig. 1. Microstructures of tested materials: (a) ZA-27 alloy, (b) Zn25Al1Si alloy, (c) Zn25Al1Si-0.03Sr alloy and (d) Zn25Al1Si-0.05Sr alloy

Due to the content of zinc and aluminium in Zn25Al alloy, it can be considered that solidification of this alloy with 1 wt. % Si occurs analogously to solidification of the conventional ZA-27 alloy, so it can be followed using the phase diagram aluminium-zinc [12]. The basic micro-constituents in the structure of Zn25Al1Si alloy (Fig. 1b) are the same as in the conventional ZA-27 alloy (Fig. 1a). The addition of silicon has resulted with some reduction in the fraction of α phase in the structure of Zn25Al1Si alloy, as well as with finer dendritic structure. Silicon particles, which differ in size, are located within the dendrites of α phase as well as in the interdendritic phase. Cavities (black regions in Fig. 1b) occurred due to the fallout of large silicon particles during metallographic preparation of samples. The addition of 0.03 or 0.05 wt. % strontium has no significant effect on the morphology of α phase, but it affects the size and distribution of silicon particles in the alloy structure (Figs. 1c and d). The silicon particles now are approximately equal in size. With an increase of the content of strontium from 0.03 to 0.05 wt. %, the size of silicon particles was reduced, while their distribution became more uniform.

Hardness measurements were performed in the Department of Materials Science of the “Vinca” institute. Five hardness readings were taken for each sample at different locations. The results of the Vickers hardness (HV5) are as follows: ZA-27 alloy (119.0); Zn25Al1Si (114.7); Zn25Al1Si-0.03Sr

(113.3); Zn25Al1Si-0.05Sr (114.0). The measured hardness of the ZA-27 alloy is in accordance with the value prescribed in the standard [9]. Alloys with silicon content (Zn25Al1Si, Zn25Al1Si-0.03Sr and Zn25Al1Si-0.05Sr alloy) show a slightly lower hardness values compared to the hardness of ZA-27 alloy. This was expected considering that ZA-27 alloy contains copper (2 to 3 wt. %) and magnesium (0.01 to 0.02 wt. %) that favourably affect hardness of the alloy. Addition of strontium had no effect on the hardness of alloys with 1 wt. % silicon.

2.2. Tribological testing

Tribological test were performed in the Tribology Laboratory at the Faculty of Mechanical Engineering in Belgrade, on the block-on-disc tribometer. The environmental conditions were: lubricated sliding and ambient air at room temperature (≈ 28 °C). A schematic diagram of tribometer is presented in Fig. 2a. Rectangular blocks of tested materials having 6 mm width and 16 mm length were used as wear test samples. Disc (hereafter referred to as counter body) of 44 mm diameter and 10 mm thickness was made of steel C60E (46 to 48 HRC). Lubrication was provided by revolving of the disc which was sunk into oil container (Fig. 2a). Lubricant was mineral engine oil (SAE 15W-40, ACEA E3). Lubricant temperature during the tests was more or less constant, and at the end of test it was ≈ 30.9 °C.

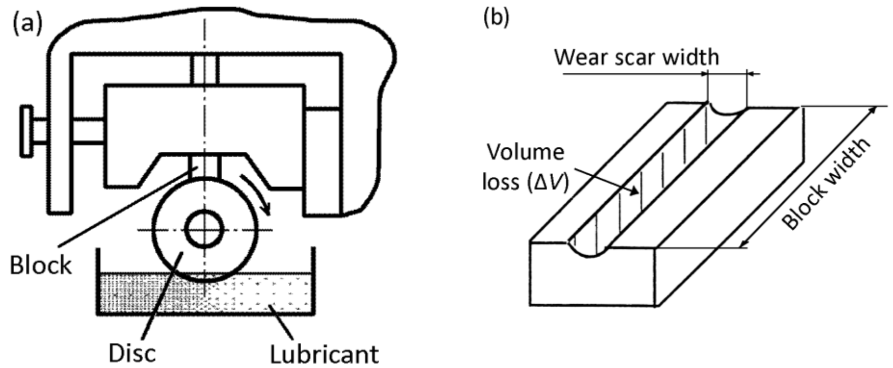

Fig. 2. Tribological testing: (a) schematic diagram of the block-on-disc tribometer and (b) block wear scar measurements

Before and after testing, both the block and the counter body were degreased and cleaned with benzene. Wear scars on pins were measured in accordance with ASTM G77 [13] with accuracy of 0.05 mm, after each test to calculate the volume loss ΔV (Fig. 2b). The values of oil temperature, friction coefficient, normal and friction force were monitored during the test and through data acquisition system stored in the PC. Tests were carried out at selected test conditions: sliding speed of 0.5 m/s, sliding distance of 1000 m and normal load of 100 N. Calculated pressure at the end of tests it was app. 5 MPa for ZA-27 alloy and app. 10 MPa for the other alloys. After testing, worn surfaces of blocks were examined by scanning electron microscope (SEM).

3. RESULTS AND DISCUSSION

This tribological investigation was just an initial one, with preliminary results and some more experiments to be done to completely understand tribological behaviour of these materials. In order to achieve a higher confidence level in evaluating test results, three to five replicate tests were run for all the tested materials. The values of the coefficient of friction are presented in Fig. 3.

Coefficients of friction were from 0.05 to 0.08, which suggest that the sliding was performed in boundary lubrication regime, since the approximate values for the boundary lubrication are from 0.05 to 0.15 [14,15]. Since the tests were performed in lubricated conditions the hardness of the materials did not have noticeable influence on friction values. Conventional ZA-27 alloy shows the highest value of the coefficient of friction of 0.07. Risdon et al. [16] tested differently obtained ZA-27 alloys and for permanent mould casted alloy the obtained coefficient of friction was between 0.03 and 0.07, but the used oil had lower viscosity and higher working temperature. In addition the sliding speed was lower and normal load differ as well.

The replacement of copper with silicon (Zn25Al1Si alloy) significantly lowers the values of the coefficient of friction (from 0.07 to 0.047). On the other hand, addition of strontium has negative effect on the coefficient of friction, i.e. with increase of Sr content coefficient of friction also increase. Similar dependence in dry sliding conditions was noticed for the Al20Si alloy modified with Sr, when Sr content exceeds some optimal value [17].

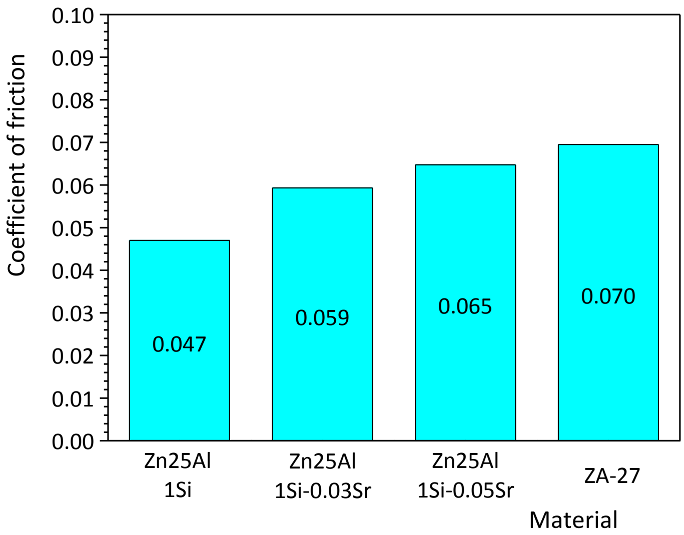

Fig. 3. Steady-state averaged values of the coefficient of friction

According to the SEM analysis (which is not presented in this paper), the dominant wear mechanism is a combination of adhesion and abrasion. Adhesive wear occur in highly-loaded, poorly lubricated sliding contacts, and was noticed at all sliding pairs. Abrasive wear was mostly pronounced at ZA-27 alloy, and this is the reason why this material showed the worse wear resistance (highest wear rate). The obtained value of the wear rate for this material of 1.41 × 10–3 mm3/m (Fig. 4) is in accordance with the data from the literature for the permanent mould casted ZA-27 alloy [16]. It should be noted that the wear process was not tracked during the tests, so the results in Fig. 4 present total wear rates.

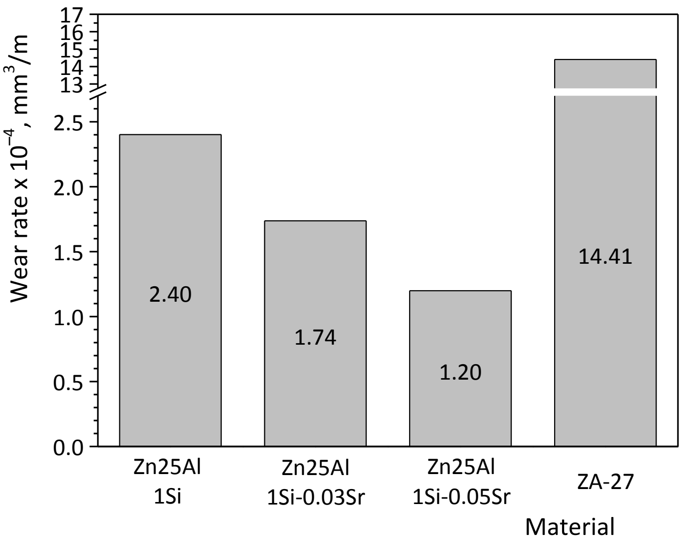

Fig. 4. Total wear rates for the tested materials

The wear rate of ZA-27 alloy was almost one order of magnitude higher than the rest of tested materials (Fig. 4), which suggests that the addition of Si instead of Cu in conventional ZA-27 alloy significantly improves its wear resistance.

Similar dependence was obtained by Savaskan and Murphy [6], who tested several Zn25Al based alloys with silicon and copper addition. The alloys were produced by gravity casting in the preheated (250 °C) steel mould. The testing conditions were as follows: block-on-disk tribometer (with conformed geometry of the block); normal load of 329 N (7.1 MPa); sliding speed of 1.73 m/s and motor oil (SAE 30) as a lubricant. The authors showed that the as-cast Zn25Al alloy containing 2.7 wt. % Si wear resistance was 4.5 to 12 times (after 1495 km and after 150 km sliding distance) higher than the same alloy containing 3.1 wt. % Cu. It is interesting to note that the wear rates of these two alloys were unproportional to its hardness, i.e. Zn25Al-2.7Si alloy showed higher wear resistance despite the fact that its hardness (81.6 HRF) were lower than the hardness of Zn25Al-3.1Cu alloy (93.7 HRF). The same unproportion was in this study, i.e. hardness of all alloys containing Si was lower slightly than ZA-27 alloy.

In the study conducted by Jian et al. [8] alloys containing Si instead of Cu also showed wear resistance one order of magnitude higher than the alloy containing Cu. All tested materials (Zn27Al, Zn27Al-2Si, Zn27Al-2Si-0.05Sr and Zn27Al-2Si-0.5Sr alloy) were sand casted. They used block-on-disk tribometer (with conformed geometry of the block); normal load of 8 MPa; sliding speed of 0.21 m/s and grease as a lubricant. The authors also showed that the modification with strontium additionally improves the wear resistance by reducing the silicon particle size. The alloy containing 0.05 % Sr showed the highest wear resistance. At the same time the alloy containing 0.5 % Sr showed wear resistance lower than the alloy that was not modified with Sr (Zn27-2Si alloy), suggesting that over modification with Sr is possible situation. Nevertheless, with further testing, by continuously increasing normal load from 4 to 18 MPa, the influence of strontium addition on wear rate becomes lower and insignificant.

In this study the influence of strontium addition in Zn25Al1Si alloy was also beneficial to wear resistance, as the Fig. 4 shows. Addition of strontium decreases the wear rate, and in case of 0.05 wt. % Sr it is twice lower. This is in accordance with the data obtained by Jian et al. [8]. The fact that the addition of 0.05 wt. % Sr decreased wear rate more than addition of 0.03 wt. % Sr suggests that the further addition of strontium may decrease the wear rate even more, which should be investigated.

4. CONCLUSION

The microstructure of the Zn25Al1Si alloy was improved with addition of strontium. The morphology of α phase was not affected, but the addition of strontium affected size and distribution of silicon particles in the alloy. With addition of strontium (0.03 wt. %) the size of silicon particle become more uniform, and with further increase of strontium content (0.05 wt. %), the size of silicon particles was reduced, while their distribution became more uniform.

The hardness of the alloys with silicon content showed slightly lower values compared to the hardness of ZA-27 alloy. Addition of strontium had no effect on the hardness of alloys with 1 wt. % silicon.

Tribological tests have confirmed that the replacement of copper with silicon in the ZA-27 alloy gave greatly improved wear resistance, and even lowers the coefficient of friction value. Strontium modification of Zn25Al1Si alloy improved wear resistance additionally, and the improvement was higher in the case of 0.05 than in the case of 0.03 wt. Sr. The coefficient of friction value was higher as strontium content increase.

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REFERENCES

1. PRASAD, B.K., Effect of microstructure on the sliding wear performance of a Zn-Al-Ni alloy, Wear, 240, 1-2, 2000, 100-112.
2. LEE, P.P. Lee, SAVASKAN, T., LAUFER, E., Wear resistance and microstructure of Zn-Al-Si and Zn-Al-Cu Alloys, Wear, 117, 1, 1987, 79-89.
3. ZYSKA, A., KONOPKA, Z., ŁĄGIEWKA, M., NADOLSKI, M., Structure and selected properties of high-aluminium Zn alloy with silicon addition, Archives of Foundry Engineering, 11, Special Issue 3, 2011, 261-264.
4. PRASAD, B.K., MODI, O.P. Slurry wear characteristics of zinc-based alloys: Effects of sand content of slurry, silicon addition to alloy system and traversal distance, Transactions of Nonferrous Metals Society of China, 19, 2, 2009, 277-286.
5. SAVAŞKAN, T., PÜRÇEK, G., MURPHY, S., Sliding wear of cast zinc-based alloy bearings under static and dynamic loading conditions, Wear, 252, 9-10, 2002, 693-703.
6. SAVASKAN, T., MURPHY, S., Mechanical properties and lubricated wear of Zn-25Al-based alloys, Wear, 116, 2, 1987, 211-224.
7. SEGAWA, T., SATO, T., KIMURA, Y., Effects of Al and Si of zinc alloys on the bearing performance under conditions of boundary lubrication, Journal of the Japan Institute of Metals and Materials, 47, 6, 1983, 515-520 (in Japanese).
8. JIAN, L., LAUFER, E.E., MASOUNAVE, J., Wear in Zn-Al-Si alloys, Wear, 165, 1, 1993, 51-56.

9. EN 12844:1998 Zinc and zinc alloys - Castings - Specifications.
10. LEHUY, H., Mechanical properties of zinc-aluminium alloys extruded in the liquid-solid state, Journal of Materials Science, 23, 8, 1988, 2943-2950.
11. MURPHY, S., SAVASKAN, T., Metallography of zinc-25% Al based alloys in the as-cast and aged conditions, Practical Metallography, 24, 5, 1987, 204-221.
12. GERVAIS, E., BARNHURST, R.J., LOONG, C.A., A. An analysis of selected properties of ZA alloys, Journal of Metals (JOM), 37, 11, 1985, 43-47.
13. ASTM G77-98 Standard test method for ranking resistance of materials to sliding wear using block-on-ring wear test.
14. RAC, A., Basics of Tribology, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia, 1991, pp. 7-23 (in Serbian).
15. HAMROCK, B.J., SCHMID, S.R., JACOBSON, B.O., Fundamental of Fluid Film Lubrication, Marcel Dekker, Inc., New York, USA, 2004, Ch. 1.
16. RISDON, T.J., BARNHURST, R.J., MIHAICHUK, W.M., Comparative wear rate evaluation of zinc aluminum (ZA) and bronze alloys through block on ring testing and field application, SAE Technical Paper 860064, 1986.
17. LIU, G., LI, G., CAI, A., CHEN, Z., The influence of Strontium addition on wear properties of Al-20 wt% Si alloys under dry reciprocating sliding condition, Materials and Design, 32, 1, 2011, 121-126.

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