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RESEARCH

ZA-27 Alloy Composites Reinforced with Al_2O_3 Particles

The ZA-27 alloy is present in the world as a material of very good tribological properties for the conditions of high loads and small sliding speeds. In recent years the research interest is increasing for development of the composite materials with that alloy as a substrate with addition of the Al_2O_3, graphite and SiC particles as the reinforcement.

In this paper are presented results of tribological investigations of composites with substrate made of the ZA-27 alloy reinforced by the Al_2O_3 particles of sizes 12 and 250 μm in quantities of 3.5 and 10 mass %. The tribological investigations were conducted on the block-on-disc tribometer with variation of the three levels of the contact load (2 daN, 5 daN and 8 daN) and three levels of the sliding speed (0.26 m/s, 0.50 m/s and 1.00 m/s), in conditions with and without lubrication.

By these tribological investigations the optimum quantity and size of the Al_2O_3 particles were established for obtaining the best characteristics form the aspect of wear, under the tested conditions. In all the test cases investigated composite materials possess significantly higher wear resistance than the pure metal substrate - the ZA-27 alloy.

Keywords: Composites, ZA-27 alloy, Al2O3 particles, wear

1. INTRODUCTION

The composite materials are created by comprising two or more materials. The initial materials have mutually different properties and their compound gives entirely new material. It has the unique, completely new characteristics, with respect to the initial components. The aim is to improve the structural, tribological, thermal, chemical or some other characteristics of the individual materials. The components are neither mixing with each other, nor diluting one in another, thus in the composite interior one can clearly distinguish two phases. One phase, called the reinforcement, provides for the strength and hardness, while the second phase is called the substrate or the connector and it surrounds and keeps together the reinforcement's particles.

The advantage of the composite materials, with respect to their substrates, reflects in improvement of the mechanical properties, primarily in increase of the specific elasticity modulus and greater hardness, increase of the wear resistance, as well as the resistance to corrosion and high temperatures, chemical resistance, sustainability and durability [1-5]. The improved properties of composites supply the possibility for their wide application. In last few decades, the multitude of composites was created, with some of exceptionally useful properties. By the careful selection of the reinforcing material and the substrate and the manufacturing process of their connecting, one can obtain the composites with properties needed for special applications. The composite materials nowadays are used in the metal working industry, automotive, airplane, electronic industries, medicine, building, etc.

The manufacturing of composites with substrates of the zinc alloys has started in the eighties of the last century in Round Oaks Laboratories and Aston University in England. As a substrate was used the ZnAl30Cu2 alloy, and as the reinforcers the short fibers made of Al_2O_3 [2]. The better properties of composites with the zinc-alloy-substrates (ZA-27 and ZA-12) with addition of the Al_2O_3 fibers were achieved by the group of researchers from MIT

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[3]. The contribution to development of composites with the zinc-alloys-substrate was also provided by the group of researchers from Israel (Israel Institute of Metals, Haifa), who established significant improvement of the wear resistance of composites with substrate made of the zinc alloy with 27 mass % of aluminum, as well as researchers from Singapore (Department of Mechanical Engineering, Singapore) who introduced new reinforcements in the substrate of the same alloy (glass, Zr_2O_3 and graphite) [4, 5]. The contribution to development of composites with the zinc-alloy-substrates was also given by the group of researchers from India (Department of Mechanical Engineering, R.V. College of Engineering, Karnataka, India) [8,9,10]. As a substrate they used the ZA-27 alloy, while as a reinforcement were added particles of graphite, SiC and zirconium, with various mass share and particles' sizes.

2. EXPERIMENTAL PART

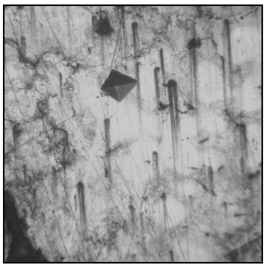
The composite materials with the ZA-27 substrate, reinforced by the Al_2O_3 particles, were obtained by the compocasting procedure, which was executed by mixing under the isothermal regime (460°C). As the reinforcers were used the Al_2O_3 powders with particles sizes of 12 and 250 μm. The smaller particles Al_2O_3 (12 μm) were infiltrated in the amount of 3 mass %, while the larger particles Al_2O_3 (250 μm) were infiltrated in the amounts of 3, 5 and 10 mass %. After the composite materials samples were obtained, it was necessary to perform the hot pressing to reduce the porosity. Form the pressed pieces were then made the samples for the tribological investigations.

The appearance of the obtained composite materials microstructures is shown in Figure 1 (magnification 200×, etched by 3% HNO_3 solution in alcohol).

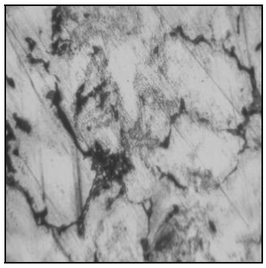
In Table 1 is shown the chemical composition of the substrate ZA-27, which was established by chemical absorption. The microgeometry of the contact surfaces of the tested composite materials is presented via the basic roughness parameters, given in Table 2.

Table 1. Chemical composition of the ZA-27 alloy

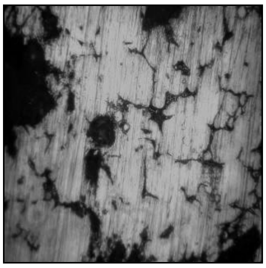
Samples	Elements, %				
	Al	Zn	Cu	Fe	Mg
ZA-27	28.47	67.77	2.51	0.145	0.011



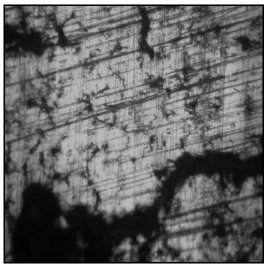
ZA-27+Al_2O_3 3%, 250μm



ZA-27+Al_2O_3 5%, 250μm



ZA-27+Al_2O_3 10%, 250μm



ZA-27+Al_2O_3 3%, 12μm

Figure 1. The ZA-27 + Al_2O_3 microstructure (magnification 200×, etched by 3% HNO_3 solution in alcohol)

Table 2. The roughness parameters of ZA-27 and tested composites

				Ra, μm	*Rz*, μm	*Rmax* μm
ZA-27 alloy				0.59	1.46	3.12
Reinforcer	Al_2O_3	Mass share, %	Particles size, μm	*Ra*, μm	*Rz*, μm	*Rmax* μm
		3	12	1.08	3.79	6.83
		3	250	0.83	2.39	6.03
		5	250	0.43	1.78	3.48
		10	250	0.93	3.32	6.51

Tests of the ZA-27+Al_2O_3 composites' tribological characteristics were of the model type and were performed on the computer supported tribometer TR-95 with block-on-disc contact geometry, in The Center for tribology at faculty of Mechanical Engineering in Kragujevac (Figure 2).

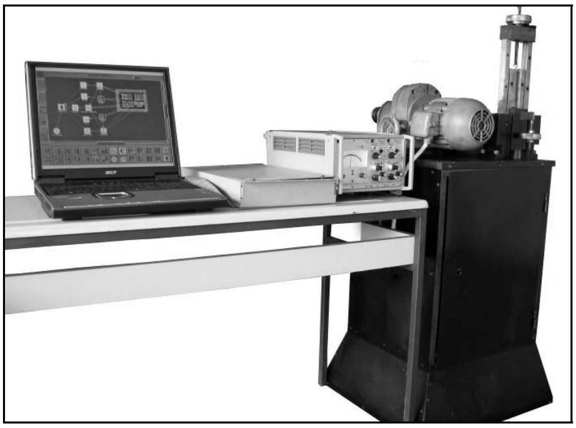


Figure 2. Tribometer block-on-disc

The test contact pair complies with the requirements of the corresponding ASTM G 77 standard. It consists of the rotational disc with diameter D_d = 35 mm and width b_d = 6.35 mm and the stationary block of the width b_b = 6.35 mm, length l_b = 15.75 mm and height h_b = 10.16 mm. Discs were made of steel Č 5432 with hardness 55 HRC with ground surfaces of roughness r_a = 0.49 mm, while the blocks were made of the tested ZA-27 + Al_2O_3 composites.

Only the basic tribological parameters were measured: force, namely the friction coefficient and the block's wear. As the main wear parameter was used the width of the wear scar on the contact surface (Figure 3). The part of the tests was aimed for obtaining the wear curves. The tests were executed both with and without lubrication, with variation of the three sliding speed levels (0.26 m/s, 0.50 m/s and 1.00 m/s) and the three contact load levels (2 daN, 5 daN and 8 daN with lubrication duration of 60 minutes and without lubrication for 10 minutes). Each experiment was repeated three times, thus the repeatability of the results could be noticed, which was found as satisfactory.

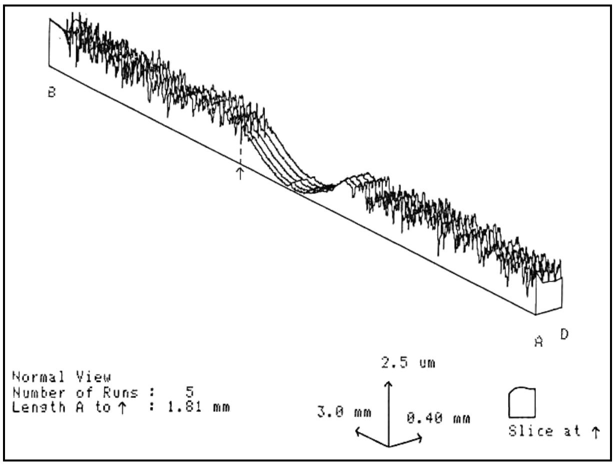


Figure 3. Profilometry of the worn portion of the block's surface

Lubrication of the contact pair was realized in such a way that disc was submersed into the oil reservoir with its lower part, thus during rotation the oil is constantly being fed into the contact zone. In all the tests with lubrication the same hydraulic oil was used, which according to standard JUS ISO 11158:2003 corresponds to the HL type and HM category (the HL type oil with the improved anti-wear characteristics, viscosity gradient VG 46 (ISO 3448)).

3. RESULTS OF TRIBOLOGICAL INVESTIGATIONS

Due to voluminous tests results, in this paper are presented only the comparative values of the wear scars under the conditions with and without lubrication. All the tests were done with three repetitions and the obtained results were then statistically processed and represented by the corresponding diagrams.

3.1. Tests with lubrication

In order to comprehend the development of the wear process with time, in Figure 4 is given the comparative representation of the wear curves for the ZA-27 alloy and composites reinforced by the Al_2O_3 particles, at sliding speeds of v = 0.5 m/s and normal force Fn = 5 daN, in conditions with lubrication.

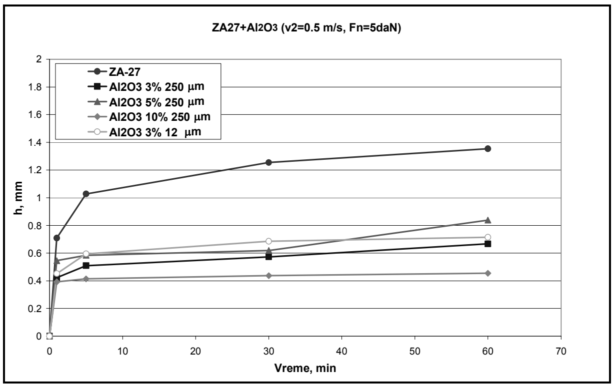


Figure 4. Wear curves - ZA-27 + Al_2O_3

The variation of the wear scar with time has the same character for all the tested materials; the only difference is in the wear level. The wear process is characterized by reaching the certain level, stabilizing and mild increase of the wear scar with time. There, the increase of wear of composites with addition of the Al_2O_3 particles in the amount of 5 mass 5 and particles size of 250 μm, after 30 minutes of friction, in all the testing conditions, is exhibiting the sudden increase, superseding the wear level of other tested composites. On the other hand, wear of the tested composites with addition of the Al_2O_3 particles is always significantly lower with respect to the ZA-27 alloy. Such a trend of the wear scar variation is noticeable for other test cases, too.

Based on the wear scar width measurements on the block after 60 minutes of friction in conditions with lubrication, the comparative histogram representation of the wear scar width variation was formed, depending on the contact conditions (sliding speed and the normal force) for all the tested materials (Figure 5).

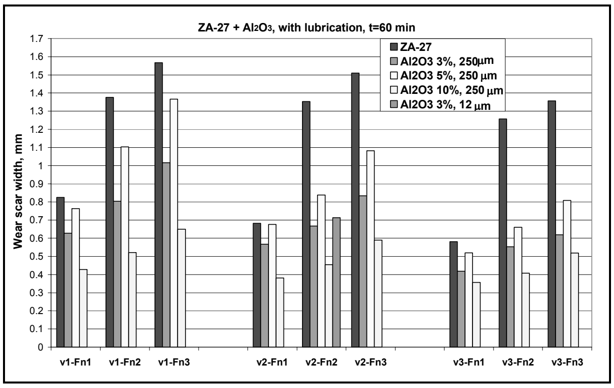
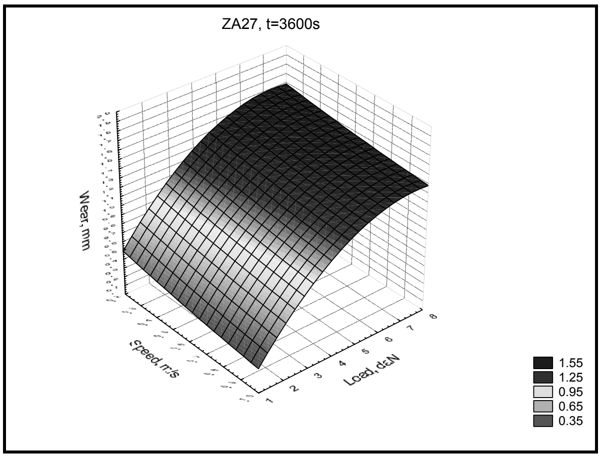


Figure 5. Wear scar width - ZA-27 + Al_2O_3

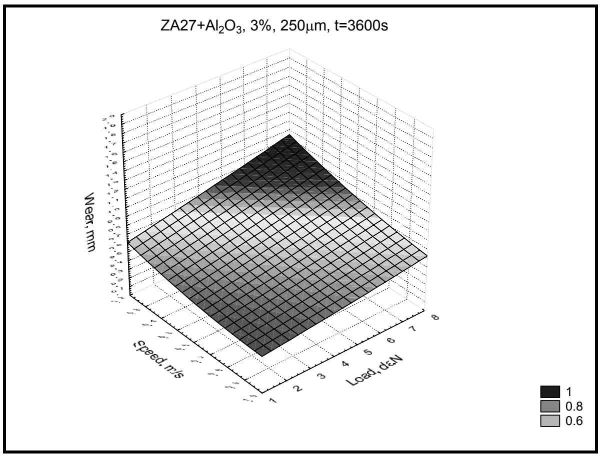
By changing the mass share and particles size of Al_2O_3, a change is realized of the wear resistance of the composite materials. By these tribological investigations the optimal amount and particles' size of Al_2O_3 was established for obtaining the best characteristics from the aspect of wear, for the tested conditions.

The conducted investigations show that the greater influence to the wear intensity is imposed by the mass share than the particles' size.

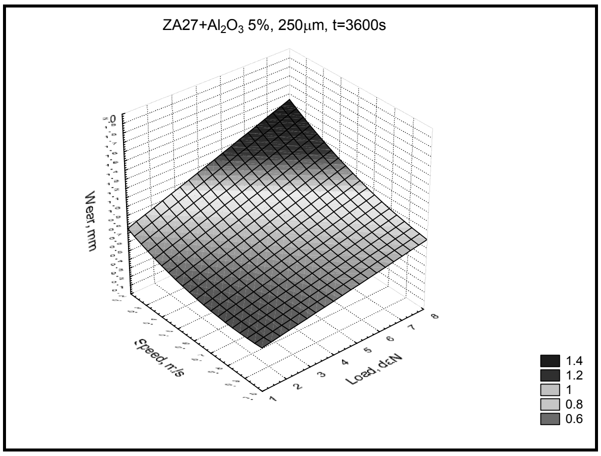
From the histogram representation of the wear scar width for the ZA-27 alloy and composites reinforced by the Al_2O_3 particles, one can clearly notice the influence of the normal load and sliding speed on the wear magnitude. This influence is identical for all the tested materials. With increase of the normal force the wear intensity is increasing, and with increase of the sliding speed the wear intensity is decreasing. The influence of the normal load to the wear intensity has approximately the same character both at smaller and greater sliding speeds.



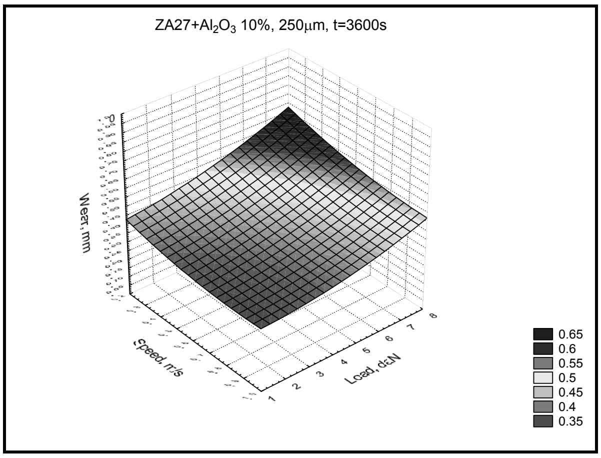
ZA-27,
$h=0.49690 \cdot Fn^{0.5064} \cdot v^{-0.10951}$



ZA-27+Al_2O_3, 3%, 250µm,
$h=0.33452 \cdot Fn^{0.31483} \cdot v^{-0.31702}$



ZA-27 + Al_2O_3, 5%, 250µm,
$h=0.25149 \cdot Fn^{0.35087} \cdot v^{0.29318}$



ZA-27+Al_2O_3, 10%, 250µm,
$h=0.46624 \cdot Fn^{0.05814} \cdot v^{0.18297}$

Figure 6. Wear scar width as a function of the sliding speed and normal load for the ZA-27 alloy and composite materials reinforced by the Al_2O_3 particles.

During tests with lubrication, the highest wear resistance was exhibited by the composite material reinforced by the Al_2O_3 particles size of 250 μm in the amount of 10 mass %, where the wear scar width decreases up to 76 % with respect to the substrate.

By analysis of the obtained results of the wear intensity investigations for the composite materials reinforced by the Al_2O_3 particles in conditions with lubrication present, the correlation dependencies were obtained in the exponential form:

$$h = C \cdot Fn^{x} \cdot v^{y}$$

In Figure 6 are graphically presented variations of the wear scar width with sliding speed and normal load, for the ZA-27 alloy and composite materials reinforced by the Al_2O_3 particles.

3.2. Tests without lubrication

Results of the wear resistance investigations for the composite materials reinforced by the Al_2O_3 particles in conditions when the lubrication is not present are given in form of histograms in Fig. 7.

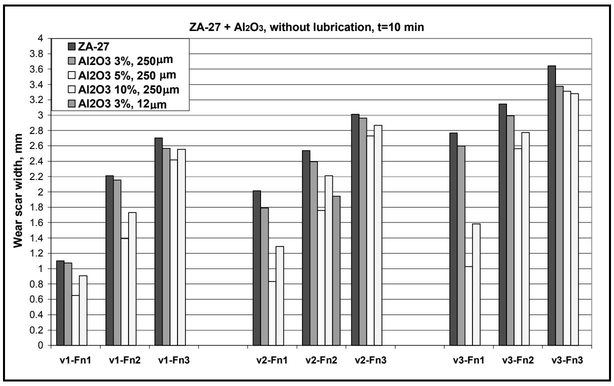
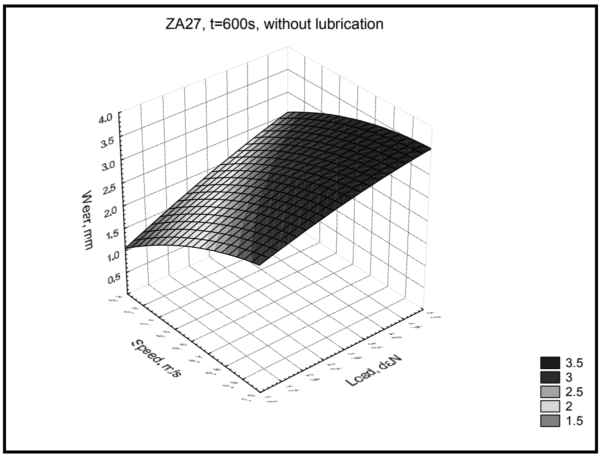
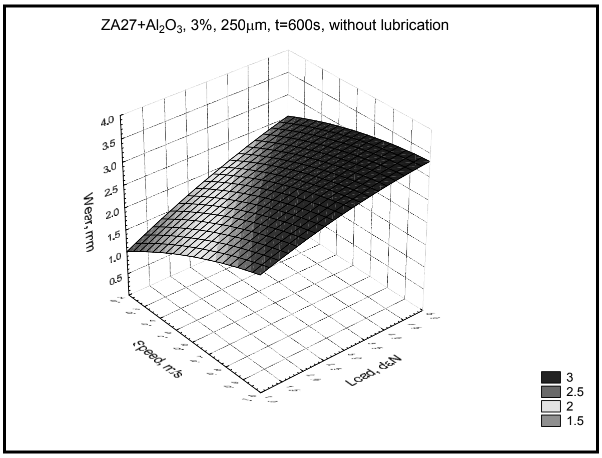


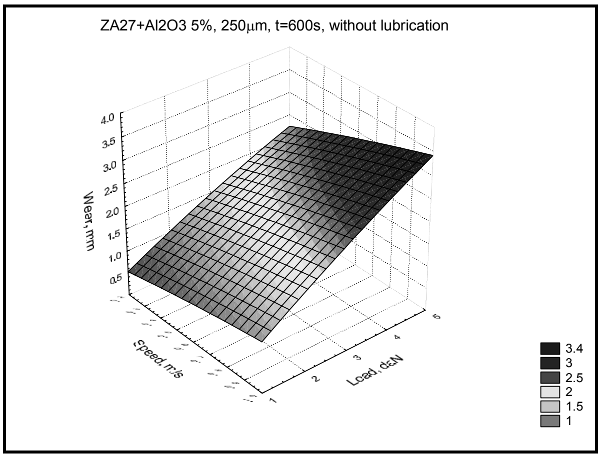
Figure 7. Wear scar width - ZA-27 + Al_2O_3, without lubrication



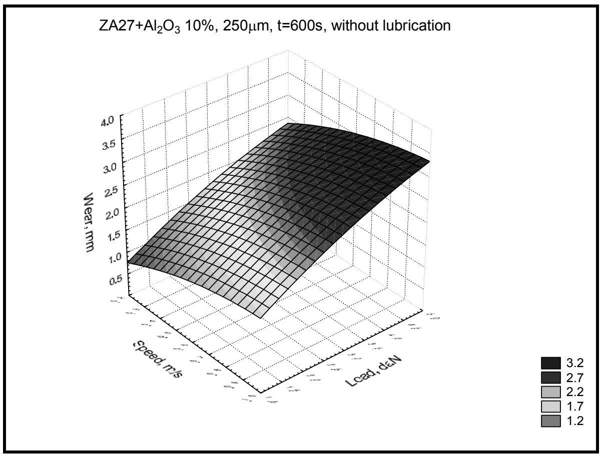
ZA27, $h=2.44331 \cdot Fn^{0.27077} \cdot v^{0.34434}$



ZA2+Al_2O_3, 3%, 250μm, $h=2.24606 \cdot Fn^{0.28143} \cdot v^{0.29667}$



ZA-27+Al_2O_3, 5%, 250μm, $h=1.03205 \cdot Fn^{0.74448} \cdot v^{0.31286}$



ZA-27+Al_2O_3, 10%, 250μm, $h=1.51854 \cdot Fn^{0.5049} \cdot v^{0.2623}$

Figure 8. Wear scar width as a function of the sliding speed and normal load for the ZA-27 alloy and composite materials reinforced by the Al_2O_3 particles, no lubrication

From the comparative presentation of the wear scar widths, one can clearly notice the nature of the normal load and sliding speed influences on the wear process in conditions without lubrications, which is identical for all the tested materials. With increase of normal load and sliding speed, the wear scar width also increases, for all the tested materials, thus the largest values are noticed at highest sliding speeds and the largest contact loads.

Differences in the wear levels, under the same contact conditions are not as prominent as in tests with lubrication, but one can clearly form the ranking from the aspect of the wear intensity. The influence of the mass share of the Al_2O_3 particles on the wear scar width in more intensive at lower contact loads. In all the conditions of tests without lubrication, the composite materials reinforced by the Al_2O_3 particles exhibit smaller wear with respect to the substrate – the ZA-27 alloy.

The highest wear resistance was exhibited by the composite material reinforced by the Al_2O_3 particles in the amount of the 5 mass % and size of 250 μm. This is especially emphasized at the lower loads, where the wear scar is decreased for over 50 % with respect to substrate. This composite exhibits also the best antifrictional properties, so it can be concluded that for these tested materials and conditions without lubrication, the good antifriction properties and good wear resistance can be achieved simultaneously.

In Figure 8 are graphically presented variations of the wear scar width with sliding speed and normal load, for the ZA-27 alloy and composite materials reinforced by the Al_2O_3 particles in conditions without lubrication.

4. CONCLUSION

Based on the conducted tribological investigations, the optimal mass shares and particles' sizes were defined for the reinforcer Al_2O_3 particles, form the tribological aspect. Results of the experimental investigations show that by varying the mass share and the size of the Al_2O_3 particles, one can influence the tribological characteristics of the tested composites with the substrate made of the ZA-27 alloy.

By investigation of the tribological characteristics of composites made with the substrate of the ZA-27 alloy reinforced by the Al_2O_3 particles, the following conclusions can e drawn:

- The tested composite materials, reinforced by the Al_2O_3 particles exhibit significantly smaller wear, with respect to the substrate;
- During the tests with present lubrication, the highest wear resistance was exhibited by the composite material reinforced by the Al_2O_3 particles of size 250 μm in the amount of 10 mass %, where the wear scar width is decreased up to 67 % with respect to the substrate;
- The highest wear resistance in tests without lubrication was exhibited by the composite material reinforced by the Al_2O_3 particles of size 250 μm in the amount of 5 mass %. This is especially prominent at lower level loads, where the wear scar width is decreased for over 50 %, with respect to the substrate. This composite also exhibits the best antifrictional properties; thus it can be concluded that for these tested materials and conditions without lubrication, the good antifrictional properties and good wear resistance can be achieved simultaneously.

This paper represents an attempt to complete the tribological knowledge related to developed composite materials with the substrate made of the ZA-27 alloy reinforced by the Al_2O_3 particles and in that way to create conditions for the broader application of these composites as the advanced tribomaterials in technical systems of various purposes. By the proper substitution of materials by the adequate composite, it is possible to lower the losses, both direct and indirect, an in that manner to realize savings, whose effects can be significant.

REFERENCES

[1.] *Z. Zhu*, A Literature Survey on Fabrication Methods of Cast Reinforced Metal Composites, ASM International USA, "Cast Reinforced Metal Composites", (1988.), 93-99

[2.] *E.J. Kubel*, Expanding Horizons for ZA Alloys, Advances Materials and Process, vol. 7 (1987.), 51-57

[3.] *I. A. Cornie, R. Guerriero, L. Meregalli, I. Tangerini*, Microstructures and Properties of Zinc-Alloy Matrix Composite Materials, "Cast Reinforced Metal Composites", (1988.), 155-165.

[4.] *N. Karni, G.B. Barkay, M. Bamberger*, Structure and Properties of Metal-Matrix Composite, J. of Mat. Scie Letters, 13, (1994.), 541-544

[5.] *K.H.W. Seah, S.C. Sharma, B. M. Girish*, Mechanical Properties of Cast ZA-27/Graphite Particulate Composites, Materials & Design, vol.16, (1995.), 270-275

[6.] *M. Babic, R. Ninkovic*, Zn-Al Alloys as Tribomaterials, Tribology in industry, Vol. 26, No 1 & 2, 2004., 3-7

[7.] *I. Bobić*, Doctoral dissertation, Razvoj postupaka prerade u poluočvrslom stanju (rheo i compo-casting procesa) i uticaj načina upravljanja na kvalitet proizvoda na bazi legure ZnAl25Cu3, Technical-Metallurgical Faculty, Belgrade, (2003.)

[8.] *S.C. Sharma , B.M. Girish, Rathnaka Kramath, B.M. Satish*, Graphite particles reinforced ZA-27 alloy composite materials for journal bearing applications, Wear 219, (1998.), 162-168

[9.] *S.C. Sharma, B.M. Girish, Rathnakar Kamath, B.M. Satish*, Effect of SiC particle reinforcement on the unlubricated sliding wear behavior of ZA-27 alloy composites, Wear 213, (1997.), 33-40

[10.] *S.C. Sharma, B.M. Girish, Rathnakar Kamath, B.M. Satish*, Sliding wear behavior of zircon particles reinforced ZA-27 alloy composite materials, Wear 224, (1999.), 89-94

[11.] *F.Kovačiček, I.Žmak*, Metal composites, MATRIB2004, Vela Luka, 2004., 349-356

[12.] *I. Bobić, M. T. Jovanović, N. Ilić*, Microstructure and Strength of ZA 27-Based Composites Reinforced with Al_2O_3 Particles,. Materials Letters, 2003.