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TRIBOLOGICAL PROPERTIES OF COMPOSITES WITH SUBSTRATE MADE OF THE ZA-27 ALLOY REINFORCED BY THE GRAPHITE PARTICLES

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Abstract. *In this paper are presented results of tribometric investigations of composites with substrate made of the ZA-27 alloy reinforced by the graphite particles of sizes 20, 35 and 100 μm in quantities of 1, 2 and 3.5 and 10 mass %. The composite materials are obtained by the compocasting procedure. Investigations were performed on the tribometer with the block-on-disc geometry in conditions with and without lubrication. Tests were done 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).*

Based on the conducted tribological investigations the optimal mass shares and particles' sizes of the graphite reinforcer as a function of the varied parameters. Results of experimental investigations show that by the change of the mass share and particles' sizes of graphite, one can positively influence in the sense of improving the tribological characteristics of the tested composites with the Za-27 alloy as a substrate.

Key words; *Composites, ZA-27 alloy, graphite particles, friction coefficient, wear.*

1. INTRODUCTION

Development of composites based in the light alloys, from many aspects, represents both the trend and the challenge of this century. The composite materials are increasingly becoming the classical materials substitutes, so the maximum of manufacturing and application of composites is expected in the middle of the 21st century. Those were the reasons that in the past ten years or so, the composites are being investigated as one of the advanced tribomaterials, due to their good mechanical and tribological properties. By the proper substitution of other materials by adequate composite material, it is possible to decrease the tribological losses, both direct and indirect, an in this way to realize savings, whose effects can be significant.

The composite material represents the solid connection of the two or more constituents, which are joined into the unbreakable connection, for obtaining the better mechanical, tribological and other characteristics. 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.

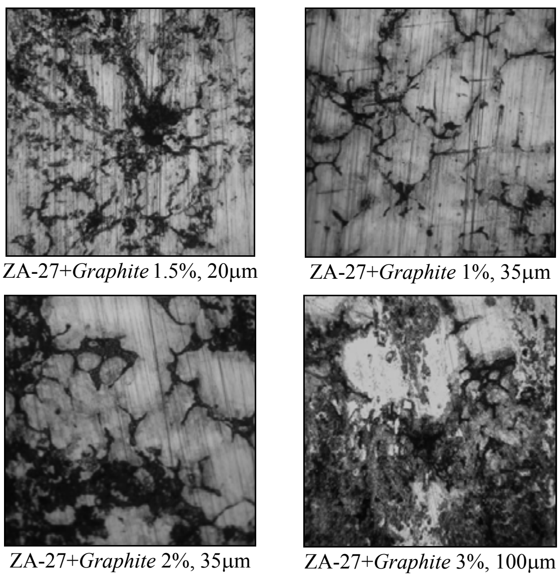
The metal matrix composites (MMC) are subject of interest from the reasons that they are capable to provide for the higher wear resistance, higher temperature limits of their substrates, increased strength, stiffness, thermal conductivity and dimensional stability. In metal matrix composites the substrate is usually made of an alloy, rarely the pure metal, while the reinforces is made of the graphite, metal and ceramic additives.

As one of the alloys, which can be used for manufacturing the metal matrix composites, is the zinc alloy with increased content of aluminum. The ZA-27 alloy is considered as the most prospective for obtaining the composites, since it is convenient as a substrate for several methods of composites manufacturing. Besides that, it is also convenient for the heat treatment and plastic forming, thus it is possible to a posteriori influence the mechanical properties of the final products.

2. EXPERIMENTAL PART

The investigated metal matrix composites with the ZA-27 substrate, reinforced by the graphite particles, were obtained by the compocasting procedure. This procedure is characteristic by the fact that the reinforcers are being added during mixing the substrate in the semi solid state. The advantage of this procedure is that for its application, the reinforcer's particles do not have to be previously prepared, i.e., the procedure can be realized by particles, which do not have to be wetted in the metal solutions. As the reinforcers are used the graphite particles of sizes 20, 35 and 100 μm. The smaller sizes particles were infiltrated in amounts of 1, 1.5 and 2 mass %, and larger size particles of graphite (100 μm) were infiltrated in the amount of 100 mass %. After obtaining the composite materials samples, it was necessary to perform the hot pressing to reduce porosity. The samples for the tribological investigations were then made from the pressed pieces.

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



ZA-27+*Graphite* 1.5%, 20μm | ZA-27+*Graphite* 1%, 35μm | ZA-27+*Graphite* 2%, 35μm | ZA-27+*Graphite* 3%, 100μm

Figure 1. *The ZA-27 + Graphite microstructure (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.

Table 1. *Chemical composition of the ZA-27 alloy*

Samples	Elements, %				
	Al	Zn	Cu	Fe	Mg
ZA-27 casted in the steel mold	28.47	67.77	2.51	0.145	0.011

Tests of the ZA-27 + Graphite 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. *The tribometer with the measurements setup and contact geometry*

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 + Graphite 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.

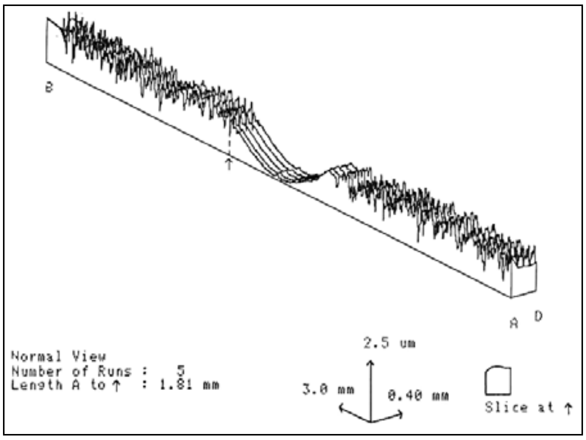


Figure 3. *Profilometry of the worn portion of the block's surface*

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 Graphite particles, at sliding speeds of v = 0.5 m/s and normal force Fn = 5 daN, in conditions with lubrication.

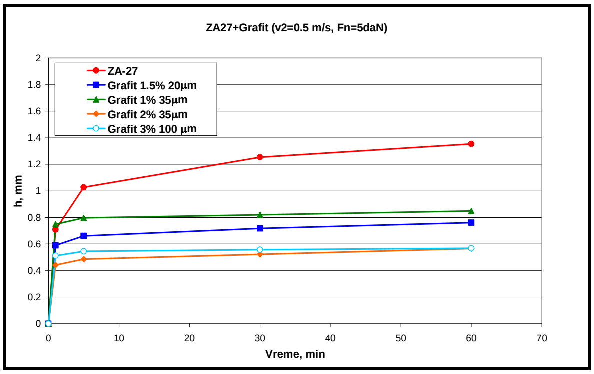


Figure 4. *Wear curves - ZA-27 + Graphite*

The most prominent point from the presented diagram is that wear, expressed via the wear scar width, of the ZA-27 alloy is far greater with respect to composites reinforced by the graphite particles, under all the tests conditions.

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 scar width of the tested composites, after entering the constant wear zone (t > 5 min), is only slightly increasing with time.

The most convincingly best wear resistance for the defined test conditions, exhibit composites reinforced by the graphite particles with higher mass share and larger particles sizes, to be exact, composite with 2 mass % and particles of 35 µm and composite with 3 mass % and particles of 100 µm. This is in accordance with results in the world journals published papers, according to which the wear level decreases with increase of the mass share of the reinforcer.

The comparative histogram representation of the wear levels in terms of the contact conditions (sliding speed and normal loading), based on the test results of the wear scar width of the ZA-27 alloy and composites reinforced by the graphite particles, in conditions with and without lubrication, after 60 min of friction duration, is presented in Figure 5.

From the figure, one can clearly notice the influence of the normal load and sliding speed on the wear magnitude. The wear intensity increases with increase of the normal force, and decreases with increase of the sliding speed. The largest wear scar widths correspond to the lowest sliding speed (v = 0.26 m/s) and to the highest values of the normal contact load (F_n = 8 daN), and at the highest sliding speed (v = 1 m/s) and the lowest load (F_n = 1 daN) the smallest wear scar widths were recorded.

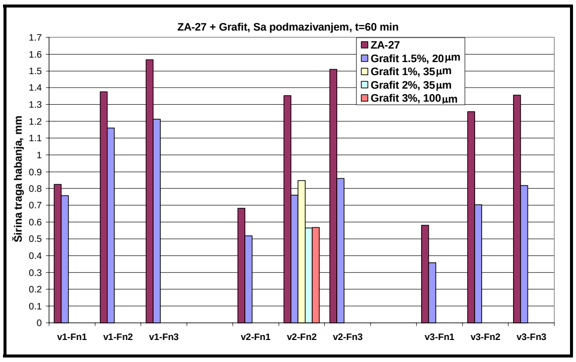


Figure 5. *Wear scar width - ZA-27 + Graphite*

During tests with lubrication, the highest wear resistance was exhibited by the composite material reinforced by the graphite 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.

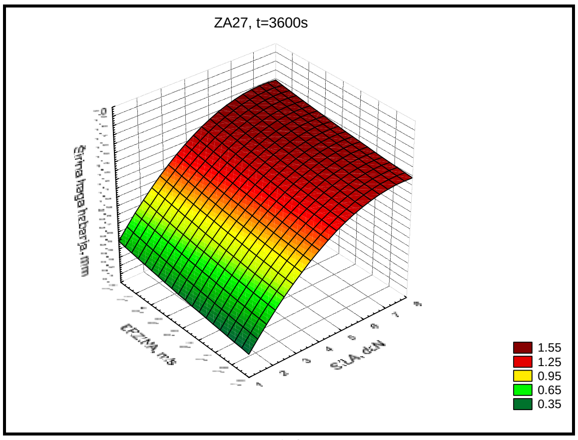
By analysis of the obtained results of the wear intensity investigations for the composite materials reinforced by the graphite particles in conditions with lubrication present, the correlation dependencies were obtained in the exponential form:

$$h=0.28432 \cdot Fn^{0.26199} \cdot v^{0.24769}$$

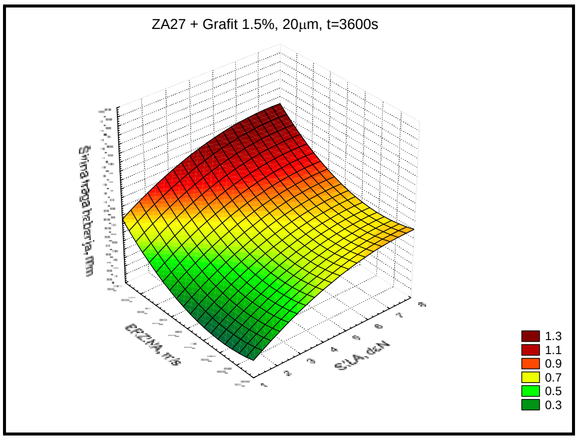
Table 2. *Wear scar width, ZA-27 + graphite*

Wear scar width, mm		$h=C\cdot Fn^x \cdot v^y$			
Contact pair		*C*	*x*	*y*	*Correlation coefficient, R*
Composite	Steel				
ZA-27	5432	0.49690	0.50647	-0.10951	0.96375
ZA-27 Graphite 1.5 mass.%, 20 µm	5432	0.28432	0.26199	0.24769	0.95479

In Figure 6 are graphically presented variations of the wear scar width with sliding speed and normal load in tests with lubrication.



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



ZA27+ Graphite, 1.5%, 20µm,
$h=0.28432 \cdot Fn^{0.26199} \cdot v^{0.24769}$

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 Graphite particles.*

3.2. Tests without lubrication

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

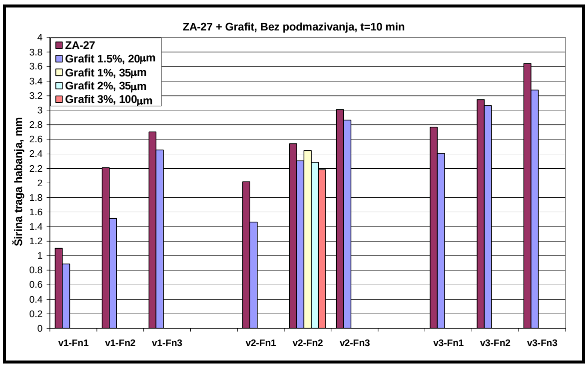


Figure 7. *Wear scar width - ZA-27 + graphite, without lubrication*

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. In all the conditions of tests without lubrication, the composite materials reinforced by the graphite 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 graphite particles in the amount of the 3 mass % and size of 100 μm.

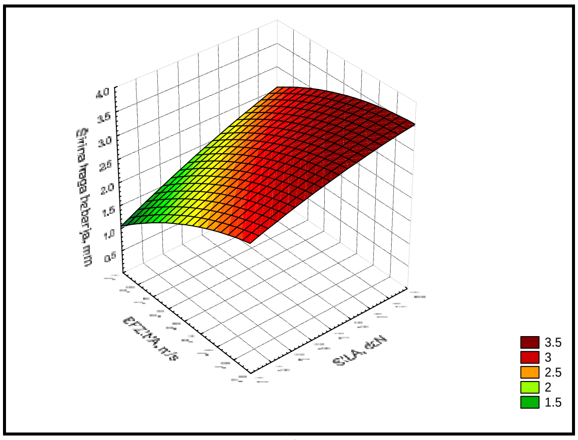
With increase of the reinforcer's particles mass share and their size in the substrate, the wear intensity decreases. Identical results were obtained by the researchers in the world.

Analytical dependences of the wear scar width on the sliding speed and normal load in tests without presence of lubrication, for the composite reinforced by the graphite particles in the amount of the 1.5 mass % and size of 20 μm is given in the form:

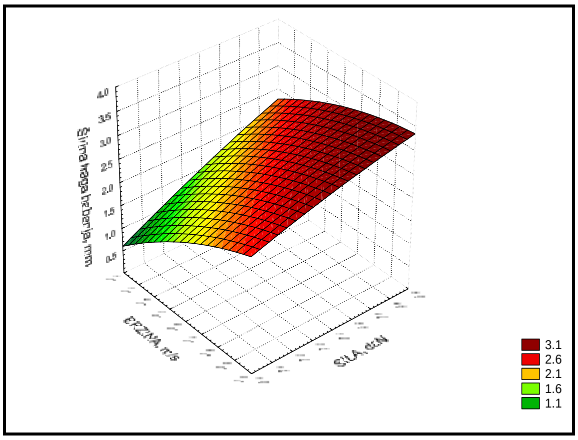
$$h=2.09172 \cdot Fn^{0.33907} \cdot v^{0.43202}.$$

Table 3. *Wear scar width, ZA-27 + Graphite, without lubrication*

Wear scar width, mm Without lubrication			$h=C \cdot Fn^x \cdot v^y$			
Contact pair						
Composite		Steel	*C*	*x*	*y*	*Correlation coefficient, R*
ZA-27		5432	2.44331	0.27077	0.34434	0.94986
ZA-27	Graphite 1.5 mass.% 20 μm	5432	2.09172	0.33907	0.43202	0.94904



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



ZA27+Graphite, 1.5%, 20μm,
$h=2.09172 \cdot Fn^{0.33907} \cdot v^{0.43202}$

Figure 8. *Wear scar width as a function of the sliding speed and normal load, no lubrication*

In Figure 8 is graphically presented the influence of the sliding speed and contact load on the wear scar width for the composite reinforced by the graphite particles in the amount of 1.5 mass % and size of 20 μm. One can clearly notice that the increase of the sliding speed and normal load lead to the wear scar width increase.

4. CONCLUSION

Based on the conducted tribological investigations, the optimal mass shares and particles' sizes were defined for the reinforcer graphite particles, form the tribological aspect. Results of the experimental investigations show that by varying the mass share and the size of the graphite 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 Graphite particles, the following conclusions can e drawn:

- The tested composite materials, reinforced by the graphite 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 Graphite 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 graphite particles of size 250 μm in the amount of 5 mass %.

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 graphite 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, 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