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ASSESSMENT OF TRIBOLOGICAL BEHAVIOUR OF ZA-27 ZINC-ALUMINIUM ALLOY BASED NANOCOMPOSITE

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Abstract: *Mechanical and tribological investigation of obtained nanocomposites is presented in this paper. As matrix material, well known tribological zinc-aluminium alloy, ZA-27 was used. Nanocomposites were obtained by compocasting procedure, while as reinforcement* Al_2O_3 *nanoparticles with average size of 20-30 nm was used. Nanocomposites with three different volume fractions were obtained. In order to get insight in structure and mechanical properties of obtained nanocomposites density and hardness measurements were performed. Tribological properties of tested materials were investigated using block-on-disc tribometer in dry sliding conditions with variation three different values of sliding speed and normal load. Wear tracks that were generated as a result of dry sliding process were analysed using optical and scanning electron with EDS microscope.*

Keywords: *ZA-27 alloy, nanocomposite,* Al_2O_3 *nanoparticles, dry sliding, friction, wear, MML*

1. INTRODUCTION

Material properties improvement is a subject of constant efforts of numerous researchers from round the world. One of the most applicable techniques to improve the material properties is obtaining composites and creating material that has different properties from origin material. Metal are wide used, mostly, due to their good mechanical properties, but improving their origin properties is an elusive goal. Common metal matrix composites have been obtained through reinforcing light metals with ceramics, in order to maintain good metallic properties (Yield strength) and get them closer properties of ceramic materials, such as great strength and thermal stability. This composite finds their application in automotive industry [1, 2].

In comparison to the micro composites there are many problems that have to be solved in order to obtain optimal nanocomposite: nanoparticles tends to agglomeration, strengthening mechanism is different, properties of nanoparticles are different than same micro particles and finally nanocomposites are much harder for examination [3]. The biggest challenges in order to obtain proper nanocomposite material are dispersion of reinforcement particles in matrix alloy, reactivity, thermal stability, wettability and price.

ZA-27 has been already known tribological alloy with wide industrial application since it has very good combination of strength, toughness and stiffness. Due to their good bearing properties it is widely used for plain bearing that operates in low load and sliding speeds conditions [4]. However, major limitation in application of these alloys is deterioration of mechanical properties on elevated temperatures above 100°C [5, 6]. Reinforcing ZA-27 alloy with ceramic particles should improve their tribological properties, thermal stability and operation temperature as well.

Nanocomposites presented in this paper were obtained using compocasting technique, due to its simplicity, flexibility and cost effectiveness, which proved to be very successful in producing micro composites [4, 7-12]. Regarding that this paper presents experimental investigation of obtained nanocomposites, based on ZA-27 alloy reinforced with Al_2O_3 nanoparticles, using compocasting technique.

2. MATERIAL

ZA-27 is the ASTM B68 standard label for zinc-aluminium alloy, which contain 25-27% of aluminium, 2-2.5% of copper, 0.0015-0.02 % of magnesium, while balance is reserved for zinc. ZA-27 was used as base alloy for obtaining nanocomposites, reinforced with Al_2O_3 nanoparticles with 1, 3 and 5% of volume fraction in matrix alloy. Average size of Al_2O_3 nanoparticles was 20-30 nm. Obtained nanocomposites were produced using compocasting technique that was conducted thought casting and hot pressing phase. Casting phase implies matrix alloy furnace melting on temperature above 570°C, then cooling down in furnace on temperature around 475°C in order to achieve semi-solid state. At this temperature mixing process starts to homogenize the mixture. At the beginning mixing speed is 50 rpm which continuously increases for 5 minutes and when mixing speed of 500 rpm is achieved infiltration of nanoparticles starts. After intensive mixing under 1000 rpm for 15 minutes obtained nanocomposites were poured in moulds that were pre-heated at 350°C. Second phase of compocasting procedure was hot pressing at 350°C and applied load of 250 MPa.

Samples preparation implied cutting, grinding and polishing under controlled condition in order to avoid temperature increase and deterioration of nanocomposite mechanical properties.

3. EXPERIMENT

Structural, mechanical and tribological experiments were performed using various laboratory equipment. Structural properties were expressed through density measurement results using Archimedes principle, while mechanical properties were examined hardness tests.

Friction and wear properties were obtained using block-on-disc tribometer, under dry sliding conditions, varying sliding speed (0.25, 0.5 and 1 m/s) and normal load (10, 20 and 30 N). Sliding distance was constant, i.e. 300m for all tribological experiments. Blocks were prepared from obtained nanocomposites and ZA-27 alloy, while steel disc were used as counter material. Detail schematic representation of tribological testing apparatus is presented elsewhere [4]. Obtained wear tracks as result of sliding process were examined using optical and scanning electron microscopy. All results from nanocomposite material testing were compared to the ZA-27 matrix alloy results. All experiments were repeated at least three times and presented values are mostly averaged values.

4. RESULTS AND DISCUSSION

Density of obtained nanocomposites and compared to the matrix ZA-27 alloy are presented on Fig. 1. Results are presented showing average values with error bars. Density measurements were performed on eight samples from each material. Measured values were analysed and averaged and presented thought histogram bars.

From presented histogram it is noticeable that highest average hardness belong to nanocomposite reinforced with 1 vol. % of Al_2O_3 nanoparticles, but due to wide range in which hardness value oscillates it is very hard to conclude that it is the nanocomposite without structural irregularities.

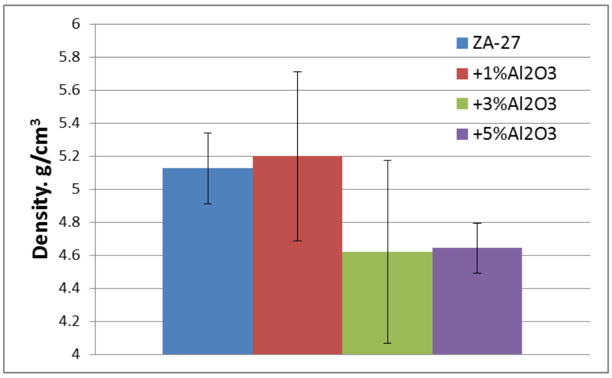
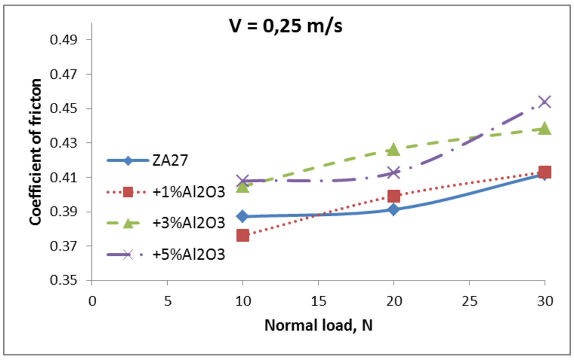


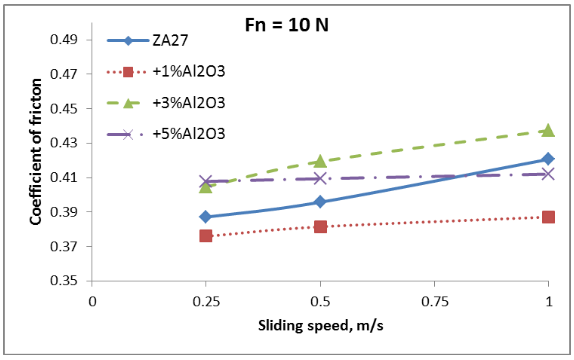
Figure 1. Density of obtained nanocomposites in comparison to the matrix ZA-27 alloy

Reasonable explanation for this result would be that there were samples with uniform distribution of reinforcement nanoparticles and samples with structural irregularities, such as agglomeration and porosity, as well. Since density of Al2O3 as a material is lower than ZA-27 alloy, it is logical that nanocomposite material has slightly lower density than ZA-27 alloy. Higher density is probably a result of hot pressing within the second phase of compocasting procedure.

In the present nanocomposites it is very hard to obtain information regarding distribution of Al_2O_3 nanoparticles within the matrix material, since matrix alloy contain large % of aluminium as constitutional material. Using SEM and EDS for microstructural analysis will not be able to distinguish alumina reinforcement from aluminium as constituent of the matrix alloy.



a)



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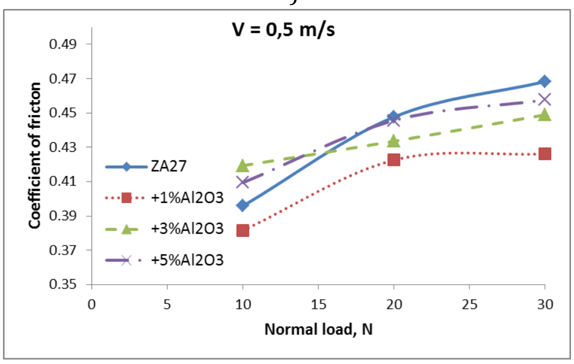

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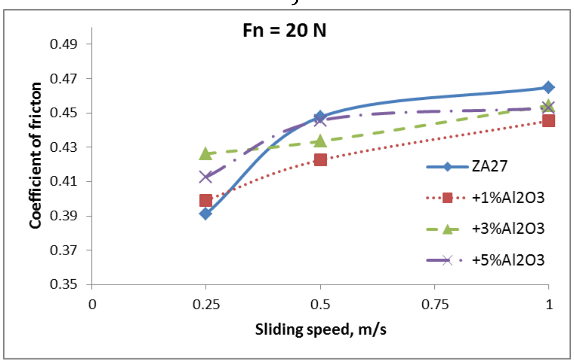
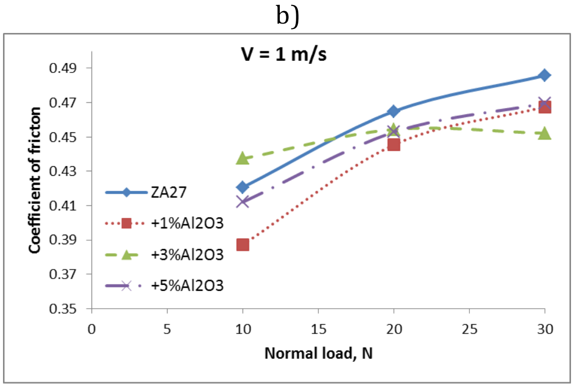
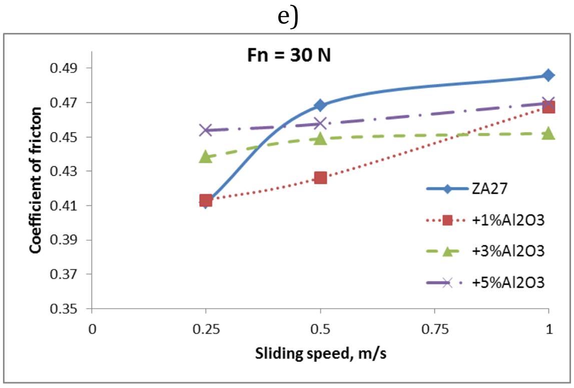


e)



c)



f)

Figure 2. Coefficient of friction of obtained nanocomposites and matrix ZA-27 alloy in comparison to normal load (a, b, c) and to sliding speed (d, e, f)

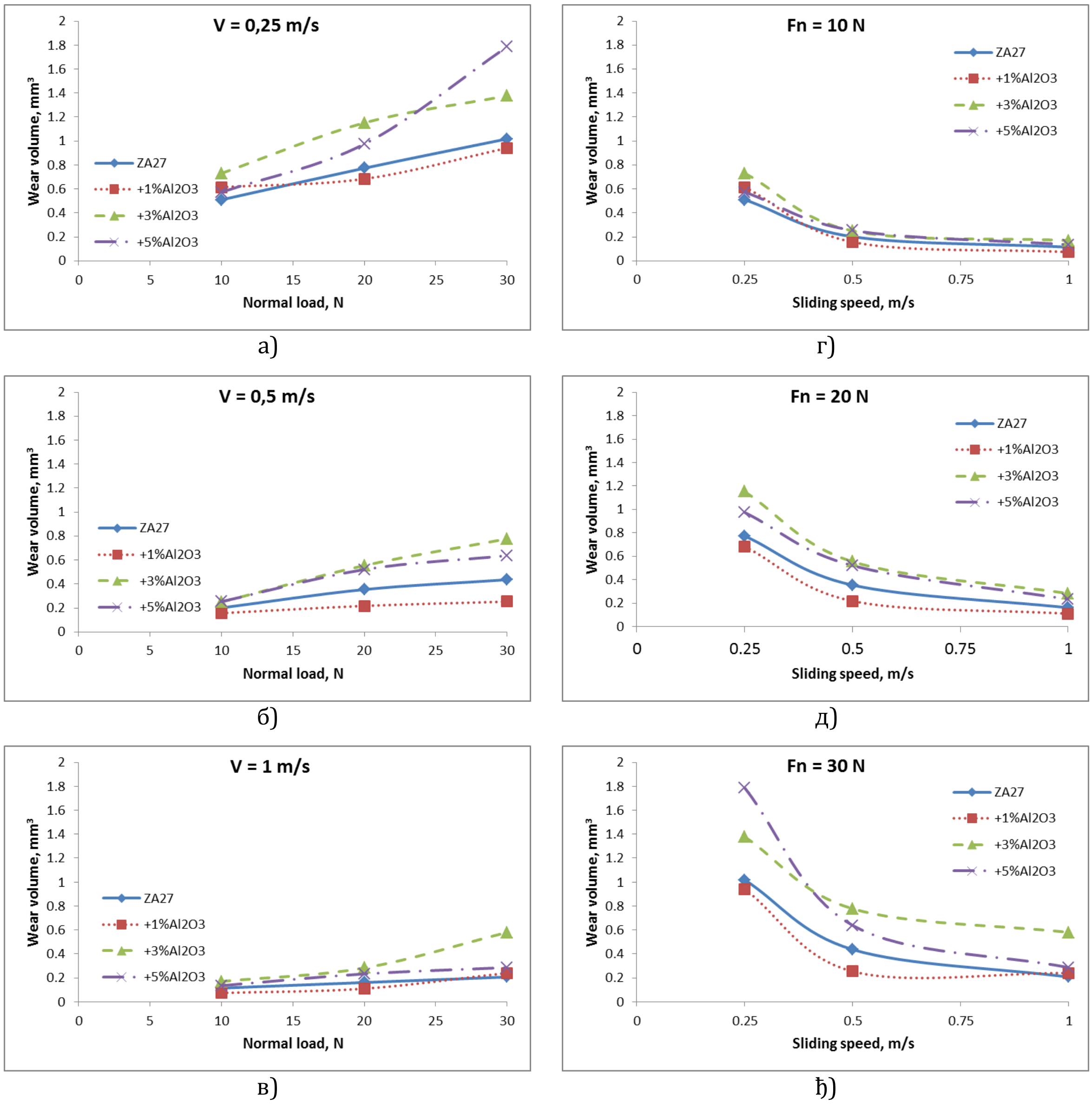


Figure 4. Wear volume of obtained nanocomposites and matrix ZA-27 alloy in comparison to normal load (a, b, c) and to sliding speed (d, e, f)

Hardness was measured using Vickers diamond tip with applied load of 50 N and those results are presented in Table 1. It is noticeable that hardness decreases with increase of volume fraction of nanoparticle reinforcement. Also, density measurement results are in correlation with hardness measurement results, except for nanocomposite reinforced with 1 vol. %.

Table 1. Hardness measurement results

	Material	Hardness, HV_5
1	ZA-27	122
2	ZA-27 + 1 vol.% Al_2O_3	114
3	ZA-27 + 3 vol.% Al_2O_3	105
4	ZA-27 + 5 vol.% Al_2O_3	102

Generally in theory presence of reinforcement nanoparticles within matrix material should improve the mechanical properties of the same though nano-recrystallization during casting [13, 14] and/or through limitation of dislocation movement [15-17]. In this both improvement methods could be countermanded with presence of structural irregularities, especially with porosity, which is obviously present within nanocomposites reinforced with 3 and 5% of reinforcement nanoparticles. When porosity is present within material structure, dislocation, generated as a result in thermal expansion difference of matrix and reinforcement, will move toward trapped gas bubbles that will contribute lower harness in comparison to the matrix alloy [18, 19].

Coefficient of friction values of matrix ZA-27 alloy and obtained nanocomposites in comparison to the sliding speed and normal load are presented on Figure 2. Presented coefficient of friction is related to the steady state values. In both cases, coefficient of friction increases with increase of sliding speed and normal load value. It is logical that coefficient of friction rises with increase of normal load, but increase with increase of sliding speed is result of contact temperature increase. Since all obtained coefficient of friction values are close to each other, it could be concluded that coefficient of friction is independent from reinforcement volume fraction value and that on micro and macro level nanoparticles has no influence on friction.

Structural irregularities have negative influence on wear resistance since nanoparticles agglomerates under normal and tangential load will be crushed into the fine abrasive particles that easily abrades both materials due to much higher hardness of reinforcement particles. Abraded steel disc is presented on Figure 3, while fine grooves are noticeable within the wear track surrounding adhesion pits (Figure 3).

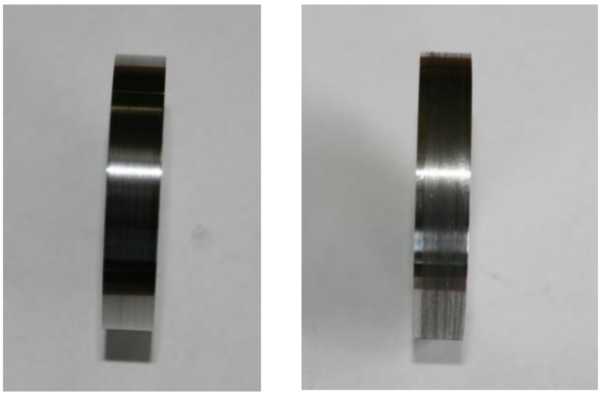


Figure 3. Disc appearance before and after sliding

Wear properties are expressed through wear volume value that is calculated from measured wear track width and already known geometry of the block (Figure 4).

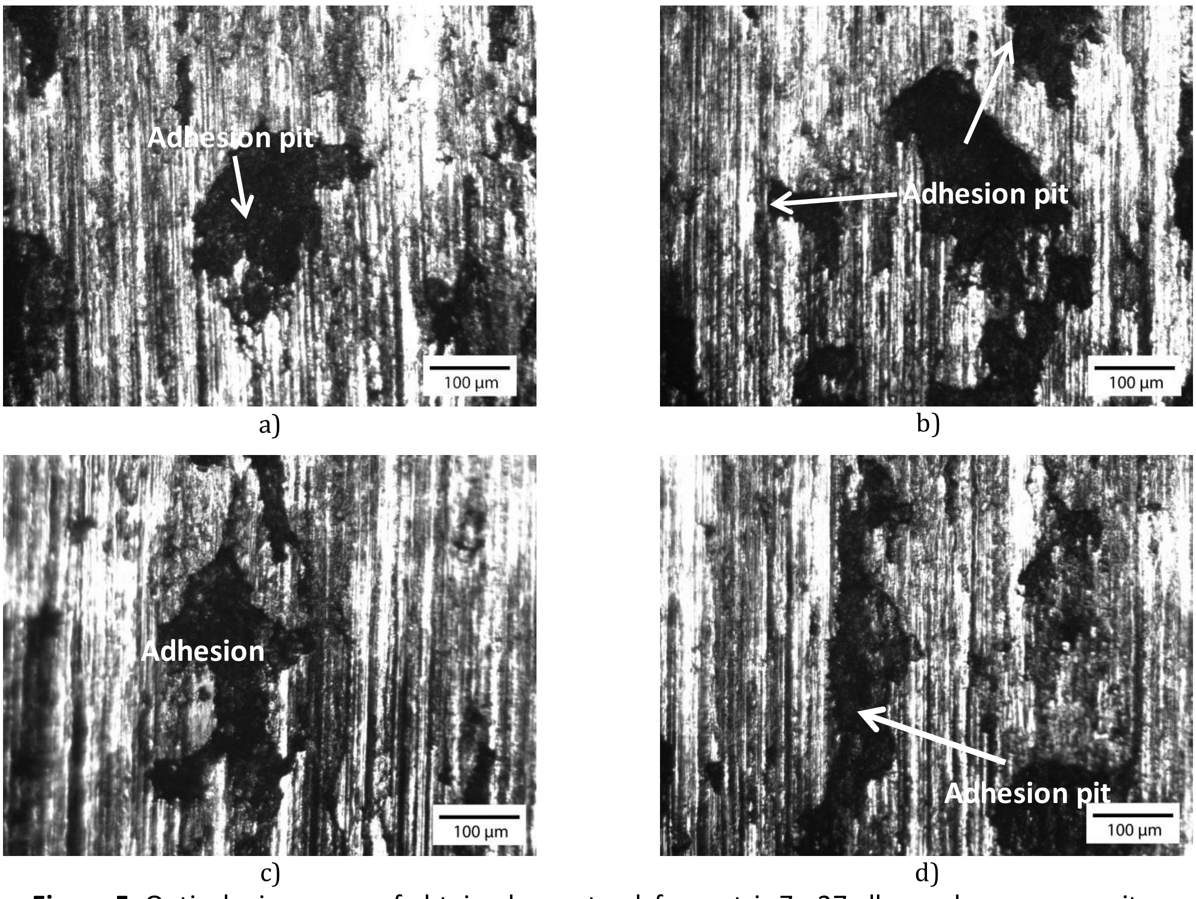
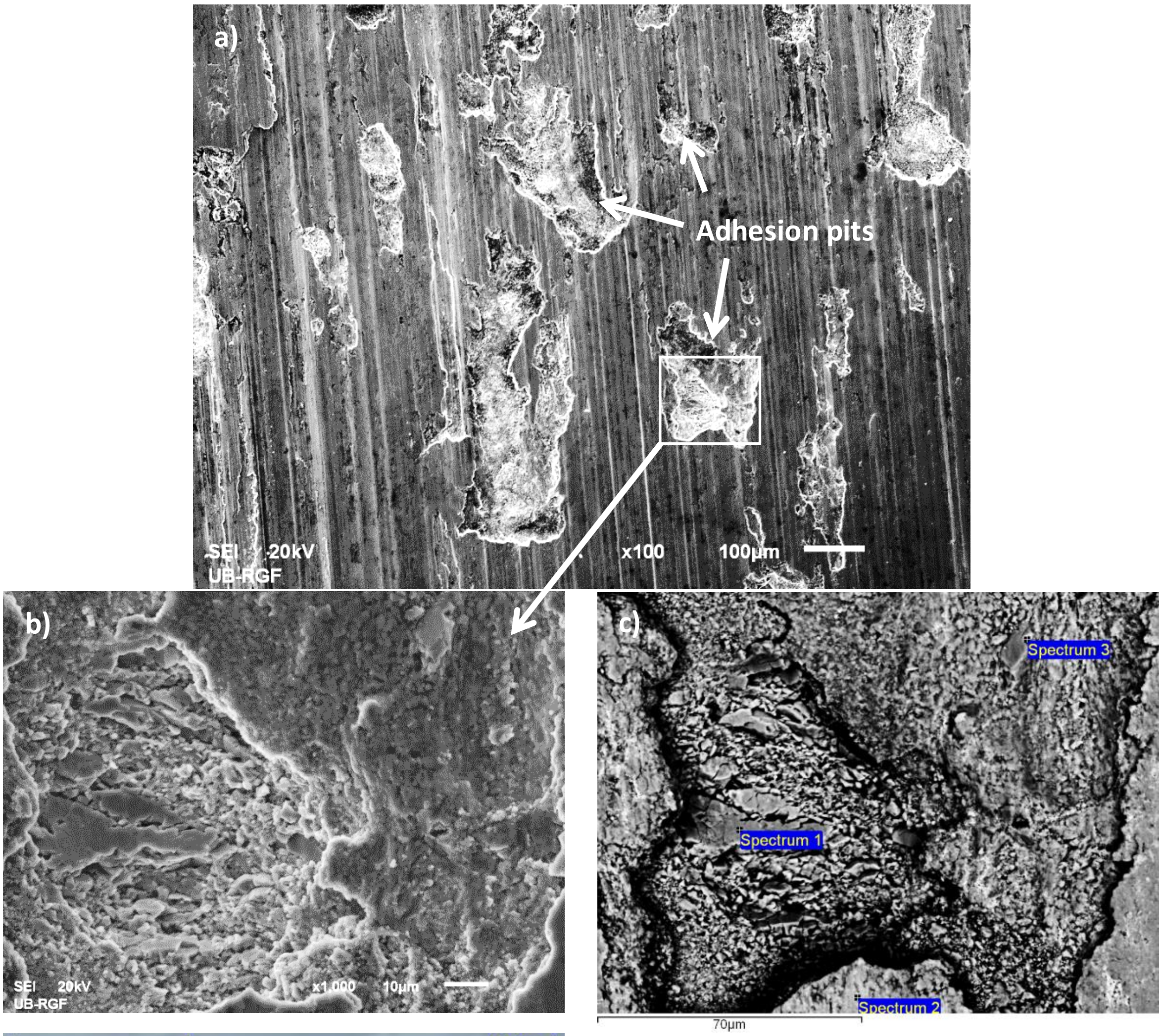
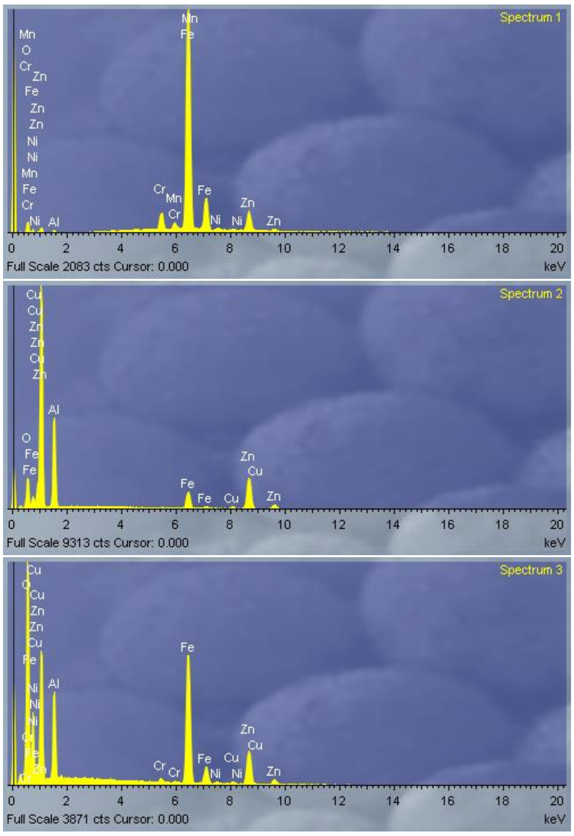


Figure 5. Optical microscopy of obtained wear track for matrix Za-27 alloy and nanocomposites a) ZA-27, b) ZA-27+1% Al_2O_3, c) ZA-27+3% Al_2O_3, d) ZA-27+5% Al_2O_3 (v=0.5 m/s; F=20 N).





O – 2.04
Al – 0.37
Cr – 3.34
Mn – 1.40
Fe – 75.89
Ni – 1.38
Zn – 15.58
Total 100.00
Values in wt.%

O – 14.35
Al – 23.08
Fe – 10.27
Cu – 2.19
Zn – 50.11
Total 100.00
Values in wt.%

O – 30.68
Al – 8.63
Cr – 0.79
Fe – 34.62
Ni – 0.65
Cu – 1.09
Zn – 23.54
Total 100.00
Values in wt.%

Figure 6. SEM and EDS analysis a) wear track of nanocomposite rainforced with 1%Al_2O_3 (a), b) enlarged adhesion pit; c) adhesion pit EDS analysis.

With increase of normal load wear volume increases, but with increase of sliding speed wear volume decreases. It is noticeable that wear volume of nanocomposite reinforced with 1 vol. % of Al_2O_3 nanoparticles is close to the value of wear volume of matrix ZA-27 alloy and in many combinations of sliding parameters nanocomposite expresses slightly better wear resistance than matrix alloy. This result is in correlation with density and hardness results. Despite lower hardness in comparison to the matrix alloy, 1 vol. % of reinforcement proved to be enough to improve wear properties of nanocomposite material, which is not the case for nanocomposites that are reinforced with 3 and 5 vol. % of reinforcement nanoparticles. In case of nanocomposites reinforced with 3 and 5 vol.% of Al_2O_3 nanoparticles, presence of structural irregularities have detrimental effect on wear resistance.

Wear tracks of were examined using optical and scanning electron microscopy. Wear tracks appearance obtained using optical microscope are presented on figure 5. Analysing presented wear tracks it is noticeable that adhesion is present as adhesion pits within the wear track that are surrounded with parallel groves that indicated on abrasion process. Adhesion pits are different in shape and size and mainly depends of material structure in surface and subsurface layer. Adhesion pits are present within the wear track of all tested materials, their number is increased in wear tracks of tested nanocomposites. In case of presence of hard particles in surface and subsurface layer, in surrounding material initial crack could occur as result of sliding process and tangential forces [20]. Also, adhesion pits could be result of hard phase detachment [4]. Abrasion occurs in mild sliding conditions, delamination and material detachment is reserved for transient phases, while under higher loads oxide layers are generated [21].

More detailed analysis of adhesion pits was performed using scanning electron microscope with energy dispersive spectre (Figure 6). EDS analysis of wear tracks and observed adhesion pits revealed presence of Fe that originate from steel disc. Presence of iron and oxygen in contact layer of tested materials suggest that during dry sliding oxide layer generates. Both contact materials react with oxygen from air. With increase of sliding speed, contact temperature raises that favours oxidation process and as a result oxide layer on the both contact surfaces will become thicker. Due to direct contact of oxidized MML arises (Mechanically Mixed Layer - Layer) [22, 23]. Presence of MML on contact surface protects origin surface from the direct contact with counterbody material and regarding that lead to lower wear of tested material with increase of sliding speed. Obtained wear results of tested material are in the corresponding with mentioned assumption, since wear volume decreases with increase of sliding speed regardless the value of applied load.

Based on EDS analysis of noticed pits within obtained wear tracks it is possible to conclude that mentioned pits are pits in MML layer that was generated on the contact surface of tested materials. Detached material from MML layer become wear debris and in that moment third body abrasion occurs.

5. CONCLUSION

Nanocomposite materials were obtained on a base of zinc aluminium alloy ZA-27, that has been already proved tribological material. Nanocomposites were obtained using Al2O3 nanoparticles (average size 20-30 nm) as reinforcement in different volume fractions 1, 3 and 5. Prepared samples were mechanically and tribologicaly analysed, and based on that results following could be concluded:

Structural irregularities such as agglomeration and porosity are noticed in obtained nanocomposites which directly influences on density and hardness, witch decreases with increase of volume fraction of reinforcement.

Presence of nanoparticles within the material structure has no influence on the frictional properties of nanocomposites, since in all testing conditions coefficient of friction of tested material has close values to each other.

Optical and scanning electron microscopy of obtained wear tracks revealed that dominant wear mechanisms were abrasion and adhesion, due to presence of adhesion pits that are surrounded with grooves parallel to the sliding direction.

SEM and EDS analysis of obtained wear tracks indicate on the presence of MML on the contact surfaces, that protects contact surface of tested materials from direct contact with counter body and on that way leads to lower wear. Thickness of MML increases with increase of sliding speed.

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