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TRIBOLOGICAL BEHAVIOUR OF A356/SIC NANOCOMPOSITE

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Abstract: *The paper presents tribological behaviour of aluminium nanocomposite A356/SiC produced by the compocasting process with mechanical alloying preprocessing (ball milling). Tribological tests were performed on tribometer with block-on-disc contact geometry under lubricated sliding conditions. Influence of amount of silicon carbide reinforcement (0, 0.2, 0.3 and 0.5 wt.%) on wear rate was investigated in the following testing conditions: sliding speed of 0.25 and 1.0 m/s, normal load of 40 N and 100 N and at sliding distance of 1000 m. Analysis of worn surface of nanocomposites was performed by using SEM equipped with EDS.*

Keywords: *nanocomposite, wear rate, silicon carbide, aluminium.*

1. INTRODUCTION

Over the last investigation of decades, nanocomposites with a metal base has been in the focus of researchers In order to find materials with the best combination of characteristics such as durability, high strength, low weight and low density. Today, due to their good properties, such as high strength and weight ratio, excellent corrosion resistance and erosion, Al-SiC nanocomposites have attracted great attention for numerous engineering applications in the automotive, military and aerospace industries [1-4]. The mentioned industries set aluminum as the basic material for the nanocomposite. In addition to the mentioned features, another advantage of using aluminum is from an ecological point of view, more precisely, components made of aluminum alloys can be easily recycled. Nanocomposites consist of a base that can be metal, ceramic or a kind of polymer, and reinforcements that can be in the form of fibers, particles or whiskers with a size up to 100 nm [5]. An exceptional class of materials are nanocomposites with an aluminum base due to their unique combinations of mechanical and tribological properties [3]. Aluminum reinforced with various particles such as carbides (SiC, B_4C, TiC), oxide (Al_2O_3, TiO_2) is suitable for different engineering purposes.

Researchers tend to use various techniques in the process of obtaining materials, variation in the content and size of the reinforcement, in simulation of real working conditions of the elements, and analysis of mechanical and tribological properties, in order of understanding the behavior of materials, and thus find the material that will respond to the task.

Yaghobizadeh O et. al for production of aluminum nanocomposites by stir casting method for applied a coating of SiC particles with aluminium in order to avoid dangerous chemical reactions with the A356 base. SiC particles with a size of 80 nm were used as an reinforcement while the size of the aluminium base particles was 50 µm. They examined the influence of the content of the SiC reinforcement in nanocomposites from 0% to 5% volume fractions, as well as the influence of temperature in the production of nanocomposites of 800°C and 850°C on strength, hardness and flexibility.

Based on the results of experiments, they concluded that generally the hardness of the samples casted at 850°C was higher than the hardness of the samples casted at 800°C. In general, they have found that by increasing the amount of SiC particles in the nanocomposite, the hardness, flexibility and ultimate tensile strength increase for the samples casted at 850°C. Then, on the basis of the SEM analysis, good particle distribution was observed which is the effect of the particle coating process. Also, they found that it is very difficult to prevent agglomeration, which they observed when testing one material, because the particles are very small [6].

Yun-hui Du et. al. in their investigations of the nanocomposites with ca Al-1.5wt.%Si aluminum alloy observed that the distribution of SiC particles significantly influences the characteristics of the composite [7]. For the study they used particles with an average particle size of 20 µm, and the volume fraction of SiC particles in the base alloy was 4.25 vol.%. In order to prove that, they have developed electromagnetic mechanical stirring and by SEM analysis, they have shown that composites can be produced with a uniform distribution of reinforcing particles by a newly created apparatus. The difference between the volume fraction of the SiC particles, at the top of the ingot and that at the bottom are both ~ 0.04 vol.%, is very small and it can be considered that uniform distribution is achieved. They achieved an significant improvement in tensile strength by about 51% and reduced the porosity of the composite. A good distribution of SiC particles in the A356 alloy without agglomeration was also demonstrated by Wu S. and others [8]. They used β-SiC particles with an average size of 40 nm, while the average size of aluminum powder was 30 µm. By application of the new complex method for obtaining the nanocomposite, the molten-metal process combined with high-energy ball milling and ultrasonic vibration methods, it was and demonstrated the improvement of the mechanical properties of the nanocomposite in relation to the basic alloy.

A higher percentage of silicon carbide reinforcement content in aluminum base for the production of nanocomposites by the stir-casting method was studied by Ashok Kumar R. and Krishnakumar T. S. The authors investigated tribological and mechanical properties of the nanocomposite with the Al 6063 base reinforced with SiC particles (0, 4, 8, 12 and 16 wt.%) with average size of 60 nm. They considered the influence of the mixing rate (400, 500 and 600 rpm) in the production of the nanocomposite on the wear and micro-hardness of the nanocomposite. Based on the analysis of the microstructure with the use of SEM, they came to the conclusion that the particles were well distributed in the base but only up to 12 wt.% SiC, and at the same time this nanocomposite showed improved mechanical and tribological characteristics.

While, when adding 16 wt.% SiC, they observed a decrease in the micro-hardness values which is the effect of forming of nanoparticles agglomeration, as well as the porosity of the nanocomposite [9].

A Prasad Reddy et. al., in addition of the silicon carbide reinforcement, also used graphite in the nanocomposite to examine the effect of applied normal load and abrasive grit particle size on two-body abrasion wear behaviour of hybrid nanocomposite. For base material AA6061 aluminum alloy was used, while the content of the reinforcement in the nanocomposite was 2 wt.% SiC and 2 wt.% Gr with an average particle size of 50 nm and 500 nm respectively. Ultrasonic-assisted stirring technique under protective argon atmosphere was used to produce nanocomposites.

The highest value of micro-hardness had a nanocomposite with 2 wt.% SiC while the hybrid nanocomposite had the best wear resistance. They concluded that the wear rate is minimal at a smaller size of abrasive grit paper, and that it is higher in coarse-sized grit paper [10]. Nidhi Sharma and Syed Nasimul Alam [11] investigated the behavior of the nanocomposite due to surface treatment. By analyzing nanocomposites with Al_2O_3 and SiO_2 base with graphite nanoplatelets (xGnP) and multiwalled carbon nanotubes (MWCNT) reinforcements they concluded that wear is influenced by geometric parameters such as the texture of the abrasive surface and the contact surface. They, also, found that SiO_2-xGnP/MWCNT composites had better wear resistance compared to Al_2O_3-xGnP/MWCNT composites. In recent years, researchers in addition to experimental tests have applied various statistical methods to plan the experiment, analyze the results, shortened the time and number of experimental performances and most importantly used them to predict the behavior of new materials [12, 13].

The aim of this study is to investigate the effect of the reinforcement on the wear of the nanocomposite in comparison with the base alloy, by applying a modified method for production of nanocomposite. The contribution of this paper is the application of a very small percentage of the reinforcement content in the A356 base.

2. MATERIAL AND EXPERIMENTAL DETAILS

2.1 Preparation of nanocomposite

In this paper, the hypoeutectic alloy A356 (AlSi7Mg0.3) was used as the base material, the chemical composition of which is shown in Table 1. The nanoparticles of silicon carbide with an average size of about 50 nm with a different weight fraction were used as a reinforcement material in aluminium alloy. The particles of silicon carbide are selected as an reinforcement because they are very common in composites with a metal base.

Prefabrication process implies mechanical alloying procedure of matrix alloy chip particles along with SiC reinforcement particles in order to reduce the generation of larger clusters before infiltration in the semi-solid alloy during the compocasting process. The prefabrication process was realised using the Turbula Type 2TC Mixer with three-dimensional eccentric movement. Mechanical alloying was carried out at a speed of 500 rpm and a time of 1 hour for each fraction of the shavings-nanopowder mixture. Then a compocasting process was carried out, which is described in [14].

It is important to note that the samples are thermally processed according to the so-called T6 regime. For these materials, mentioned regime consisted of 5 hours of heating under liquid conditions at 540°C, with subsequent quenching in water, followed with artificial aging that implies heating the samples at 160° C for 6 hours and quenching in water.

2.2 Specimen preparation

The metallographic investigation of the microstructure was done due to surface analysis of the prepared samples of nanocomposite and the basic alloy. The samples prepared from cast nanocomposite were polished with sandpaper of P1000, P2000 and P3000 granulation, with approximately the same parameter values: polishing time and polishing speed.

Table 1. Chemical composition of A356 alloy (wt.%)

Chemical element	Si	Cu	Mg	Mn	Fe	Zn	Ni	Ti	Al
Element content (wt.%)	7.20	0.02	0.25	0.01	0.18	0.01	0.02	0.11	the rest

Figure 1. Polisher with mark MetaServ 250

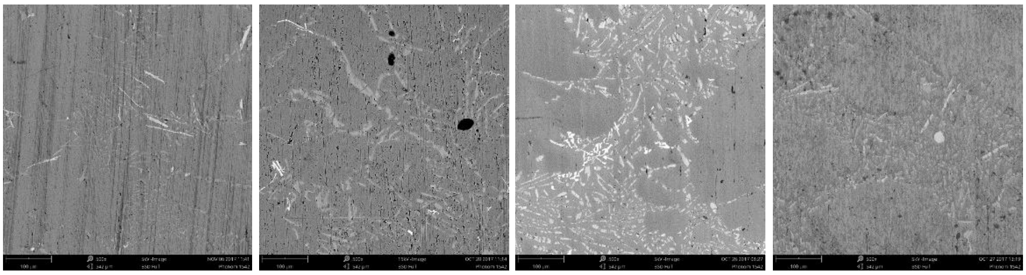
Then polishing the surfaces was performed by an emulsion with abrasive grains of 1 µm. Preparation of samples on this polisher is simple because it provides the possibility of cooling with water supply by means of a water jet, thus preventing surface heating.

The surface appearance after the sample preparation is shown in Figure 2.

2.3 Tribological testing

In order to investigate the tribological characteristics of nanocomposite, tests were performed on a computer-supported tribrometer TPD 95, with block-on-disc contact geometry. The tests were carried out under lubrication conditions in accordance with the ASTM G77-83 standard. The contact pair consists of a disc with diameter 60 mm and width of 10 mm and block with size of 6×16×12 mm. The block materials are the tested aluminum nanocomposites, while 42CrMo4 steel, with hardness of 50-55 HRC, was used for the disc material. Contact between the elements of the tribomechanical system is line contact. Outputs that can be tracked in addition to wear and friction coefficient are lubricant temperature, contact temperature as well as sliding distance. Surface roughness measurements for tribological testing were performed on the computerized measuring device Talysurf 6. The surface roughness of the blocks and discs was approximately Ra = 0.2 and 0.4 µm, respectively.

Tribological tests of A356 aluminum alloy and aluminum nanocomposites were carried out under lubrication conditions on a sliding distance of 1000 m. The lubricant used in this experimental test was a gear oil, viscosity of which is 220 mm^2/s. In the realization of tribological tests factors: load (40 N and 100 N) and sliding speed (0.25 m/s and 1 m/s) were varied to monitor the behavior of the material. Also, the content of the reinforcement particles in the base alloy was varied (0.2 wt.% SiC, 0.3 wt.% SiC and 0.5 wt.% SiC). Figure 3 shows a tribometer used for experimental testing of the nanocomposite.



a) b) c) d)

Figure 2. Surface of nanocomposite with magnification x500 a) A356, b) A356/0.2 wt.% SiC, c) A356/0.3 wt.% SiC and d) A356/0.5 wt.% SiC

Figure 3. Tribometer testing

After the completed tests, the worn surface of the samples was observed using a scanning electron microscope and an EDS analysis was performed to determine the chemical composition of the nanocomposite.

3. RESULTS AND DISCUSSION

The results of tribological tests of the nanocomposite and A356 base material are shown in the following diagrams (Figs. 4-7). The effect of the silicon carbide reinforcement in the A356 alloy was studied by monitoring the wear of the material, as well as analyzing the worn surfaces using SEM and EDS analysis.

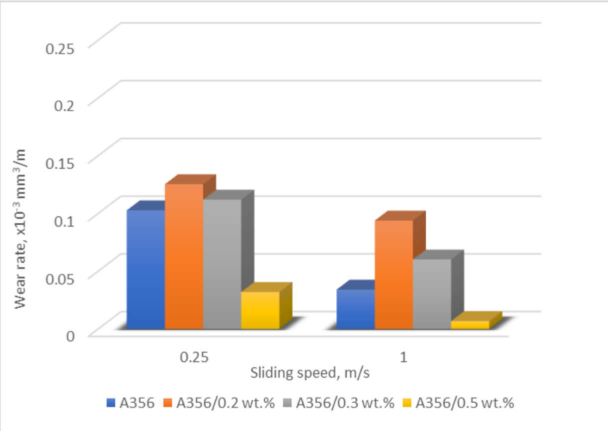


Figure 4. Wear rate at load of 40 N

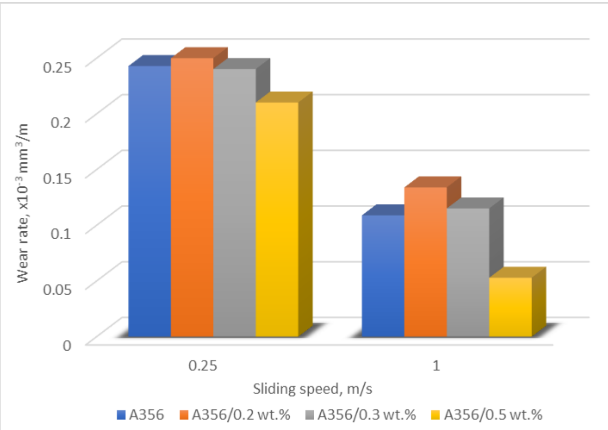


Figure 5. Wear rate at load of 100 N

Forming of the diagrams is based on the measurement of the wear track after 1000 m and the calculation of the wear rate. By comparing the diagrams (figures 4 and 5), the wear rate increases with an increase of load from 40 N to 100 N for all tested materials. This finding is in accordance with the literature data for dry sliding conditions [15-21]. The increase of wear rate is particularly present in the nanocomposite A356/0.5 wt.% SiC at a sliding speed of 0.25 m/s. Then, by increasement of sliding speed wearing rate is reduced, which is justified by the fact that in this test at a higher sliding speed for loads of 40 N and 100 N there was mixed lubrication. Increase in the wear value of the nanocomposites with 0.2 and 0.3 wt.% SiC reinforcement in relation to the base alloy is probably due to the existence of structural imperfections, most likely porosity, which is characteristic for nanocomposites [9, 22-24]. The influence of the reinforcement content on the wear rate, in this study, is the smallest. It is concluded that the improvement of wear resistance occurs only with the content of 0.5 wt.% SiC reinforcement compared to the base alloy of the nanocomposite. The assumption is that an insufficient amount of silicon carbide particles was used in the base to achieve a reinforcement of the base. Also, it can be said that in the nanocomposite with 0.5 wt.% SiC reinforcement, the percentage of the reinforcement is sufficient to annul-cancel the influence of the structural imperfection existence. The same conclusion can be made when it comes to a load of 100 N.

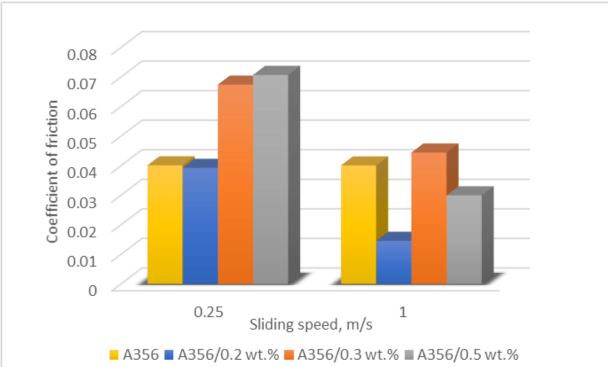


Figure 6. Friction coefficient at load of 40 N

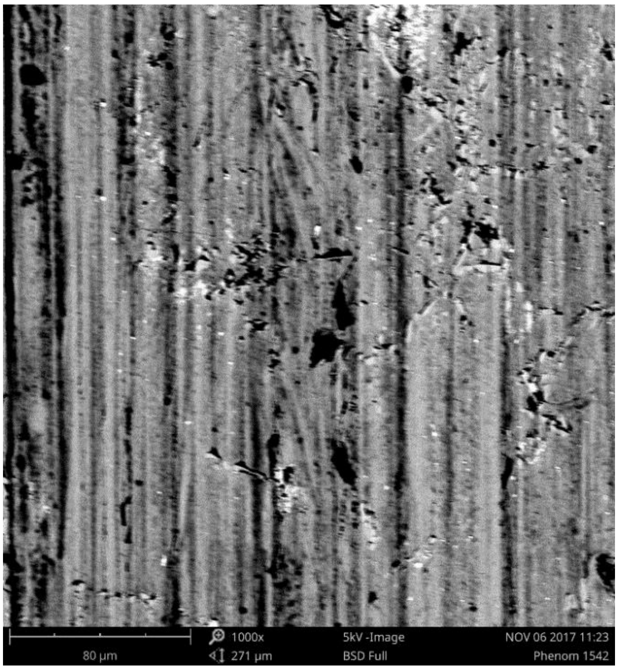
Regarding to the friction coefficient, it is noted that with the increase of sliding speed the friction coefficient decreases, for each observed material individually, which is expected. For the influence of the load, the dependence of the tested materials cannot be observed, because on the basis of the friction coefficient value it is noticed that there was mixed lubrication. In this type of lubrication, it happens that in some segments of the contact there is a separation of the contact surfaces.

This type of lubrication occurs in gear pairs, ball and roller bearings, and even with conventional bearings [25].

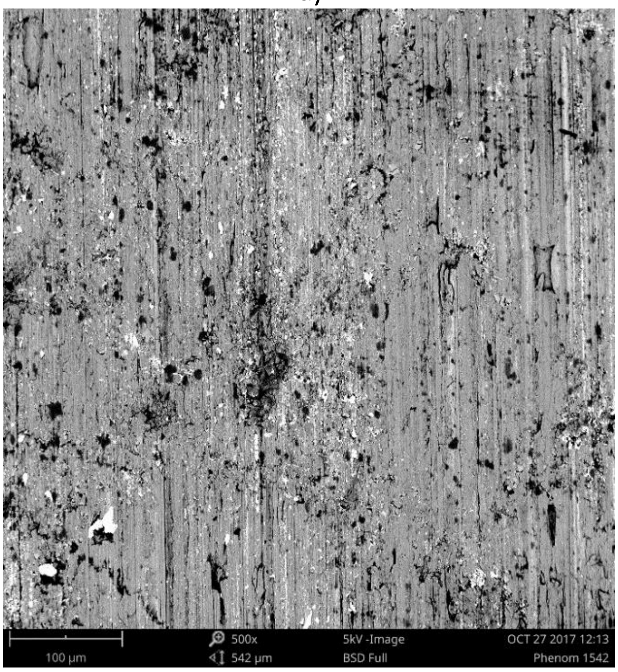
By analyzing the experimental results, the dependence between the reinforcement content and the friction coefficient cannot be established. What can be observed from the diagram is that with the increase of the load, the friction coefficient increases, but only at a sliding speed of 0.25 m/s for materials A356 and A356/0.5wt.% SiC. While at a 1 m/s sliding speed, it is observed that the friction coefficient decreases with increasement of the load. The consequence of the difference in friction coefficients is definitely the existence of structural imperfections, which is confirmed by the large differences in the measured values of the friction coefficient.

After tribological testing, wear tracks of tested materials were observed using SEM analysis. Figure 8 shows the wear tracks of the A356 base material (Fig. 8a) and the nanocomposite with 0.5 wt.% SiC (figure 8b) formed under test conditions of F = 100 N and v = 0.25 m/s.

In the previous figures of the worn surfaces of the observed samples, the grooves who follow the sliding direction can be observed. The worn surfaces of the tested materials contain white and gray tracks in certain areas, suggesting the transfer of material from the steel disk to the tested block. White tracks represent iron oxide in the surface layer of the nanocomposite. This phenomenon is present in all investigated nanocomposites and base alloy. By observing the morphology of the worn surfaces, it is noted that the grooves that occur during sliding are parallel to the sliding direction, which indicates that the abrasion wear is present. In addition to abrasion, adhesion appears as the dominant wear mechanism in the investigation of these materials. Comparison of results with the investigation of other researchers is not possible because they performed tribological testing of nanocomposites in conditions without lubrication.



a)



b)

Figure 8. Worn surface of: (a) matrix alloy A356 and (b) nanocomposites with 0.5 wt.% SiC

The presence of nanoparticles led to a reduction in wear which was conclude also in [26] because it was observed that the number and depth of the grooves were smaller in the nanocomposite A356/0.5 wt.% SiC compared to the base alloy. Similar results on the behavior of composites with aluminum base and reinforced with SiC nano particles, have been published in [27,28].

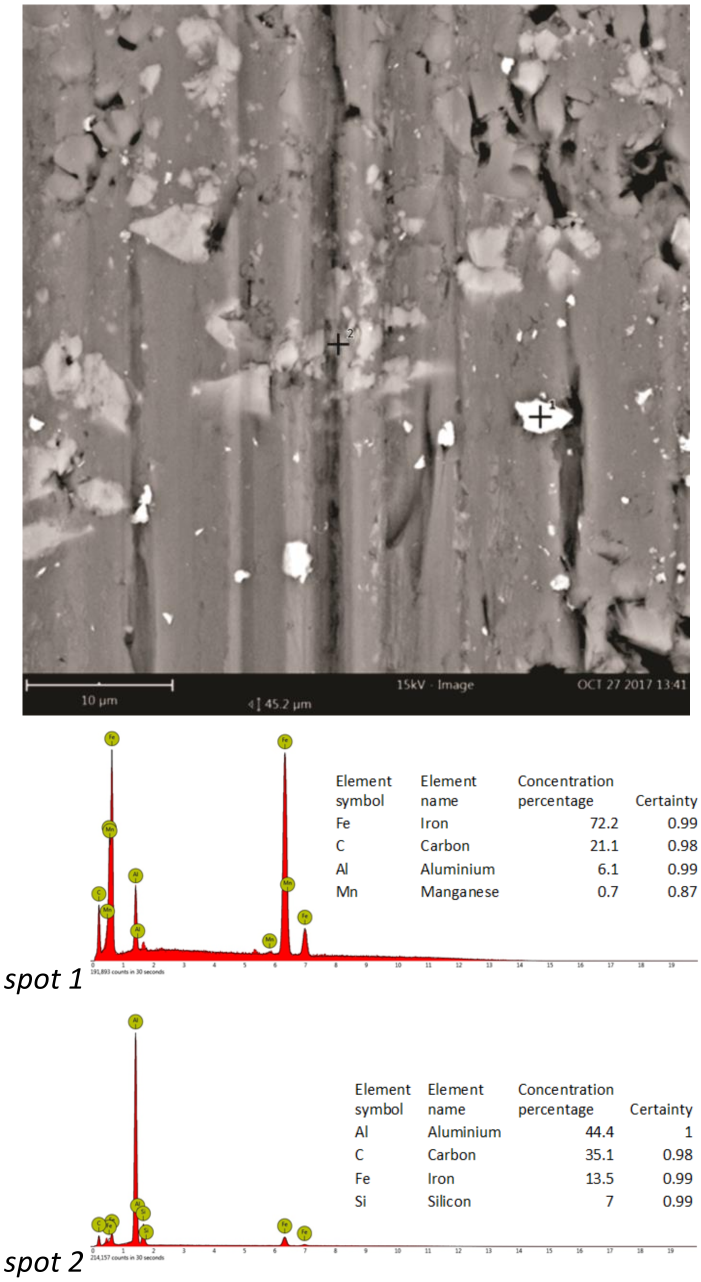


Figure 9. EDS analysis of the wear track of A356/0.5wt.% of nano-SiC

The EDS analysis was done in the wear track of the nanocomposite (Fig. 9), which was created under testing conditions of load of 40 n and sliding speed of 0.25 m/s. The EDS analysis confirmed that the brighter surfaces on the worn surface beside the aluminum element contain a significant amount of iron. This confirms that there is a tranfer of material moving from the steel disk to the tested blocks.

4. CONCLUSION

Aluminum composites reinforced with silicon carbide nano particles were produced by a modified compocasting process with different wt.% of SiC particles in the A356 base alloy. Experimental testing was carried out on a block-on-disc tribometer under lubrication conditions to examine the effect of the reinforcement on the tribological characteristics of the nanocomposite. Based on this research, the following conclusions can be made:

- Nanocomposites are successfully prepared by a modified compocasting process.
- The content of ceramic particles of silicon carbide in the A356 alloy should only be above 0.3 wt.%, in order to improve the wear resistance of the

nanocomposite regarding to the base alloy. More precisely, in the nanocomposite with 0.5wt.% SiC, the effect of the reinforcement has diminished the existing structural irregularities which can be observed based on the wear.

- The dependence of the effect of the reinforcing particles on the friction coefficient of the material could not be established. The only thing that can be noted is that the increase in the sliding speed decreases the friction coefficient for each material that was investigated.
- An analysis of the surface surfaces with SEM and EDS nanocomposites revealed abrasion as the main wearing mechanism, which is characterized by the formation of grooves. Furthermore, based on the transfer of material from the disc to the tested samples, it is concluded that besides abrasion there is, also, adhesion.
- The future investigations will focus on precise determination of the density and porosity of the materials in order to confirm the results that are obtained.

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