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RESEARCH

Nanotribology Investigations of Composites Based on Za-27 Alloy Reinforced by Al_2O_3 Particles

Results of tribological investigations of composites based on ZA-27 alloy, reinforced with Al_2O_3 particles of 250 μm size, with three different mass shares percentage as follows: 3 %, 5 % and 10 %, are presented in this paper. Tribological investigations are realised on nanotribometer with linear reciprocating module setup. Four levels of normal contact loads are varied during testing (10 mN, 50 mN, 100 mN and 120 mN) and three levels of speed (10 mm/s, 20 mm/s and 30 mm/s), with no lubrication.

Keywords: Composites, ZA-27 alloy, Al_2O_3 particles, friction coefficient, nanotribology

1. INTRODUCTION

During last years, composites have been extensively investigated as advance tribomaterial due to their good mechanical and tribological characteristics. By proper substitution of certain material with adequate composite material, it is possible to decrease tribological losses – direct and indirect ones and to realise savings with significant effects.

Metal matrix composites (MMC) have been subject of investigations due to their increased wear resistance and increased temperature bounds compared to their raw material basis and also because of their increased hardness, rigidity, temperature conductivity and dimensional stability. For metal matrix composites matrix is usually made of alloy, rarely of pure metal and reinforcing material is comprised of carbon, metal or ceramics.

Type of alloy that is successfully used for metal matrix composites production is a type of Zinc alloy with increased percentage of Aluminium. ZA-27 alloy is considered to be the most promising one for composite material production because it is suitable as a raw material basis for several production methods. It is also suitable for heat treatment and plastic forming in such a way that it is possible to influence afterwards the mechanical properties of obtained products.

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By analysing ZA-27 alloy solidification it is determined that the optimal procedure for production of composite with ZA-27 alloy basis is compocasting procedure. This procedure is characteristic by the fact that ceramic reinforcement materials are added during mixing of metal basis which is in a semi-solid state. Advantage of such a process is due to reinforcement materials particles not being specially prepared, that is, it can be done with particles which are not wettable in a metal melt. Further processing of the material produced by compocasting process is possible by application of technologies such as casting under pressure, moulding, rolling and forging [1].

2. EXPERIMENT

2.1 Microstructure and microgeometry

Tested composite materials with ZA-27 alloy basis, reinforced with Al_2O_3 particles are obtained by compocasting method. Al_2O_3 powder, with 250 μm size of particles, is used for reinforcement. Al_2O_3 particles are infiltrated during the mixing of metal base in semi-solid phase. Particles are infiltrated in quantities of 3, 5 and 10 mass percentage. After composite materials samples producing, hot moulding is done in order to decrease porosity. From produced materials, samples for tribological testing are obtained.

Table 1. Chemical composition of ZA-27 alloy

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

Chemical composition of ZA-27 alloy raw material is given in Table 1.

Microstructure of ZA-27 alloy and obtained composite materials are shown in Figure 1.

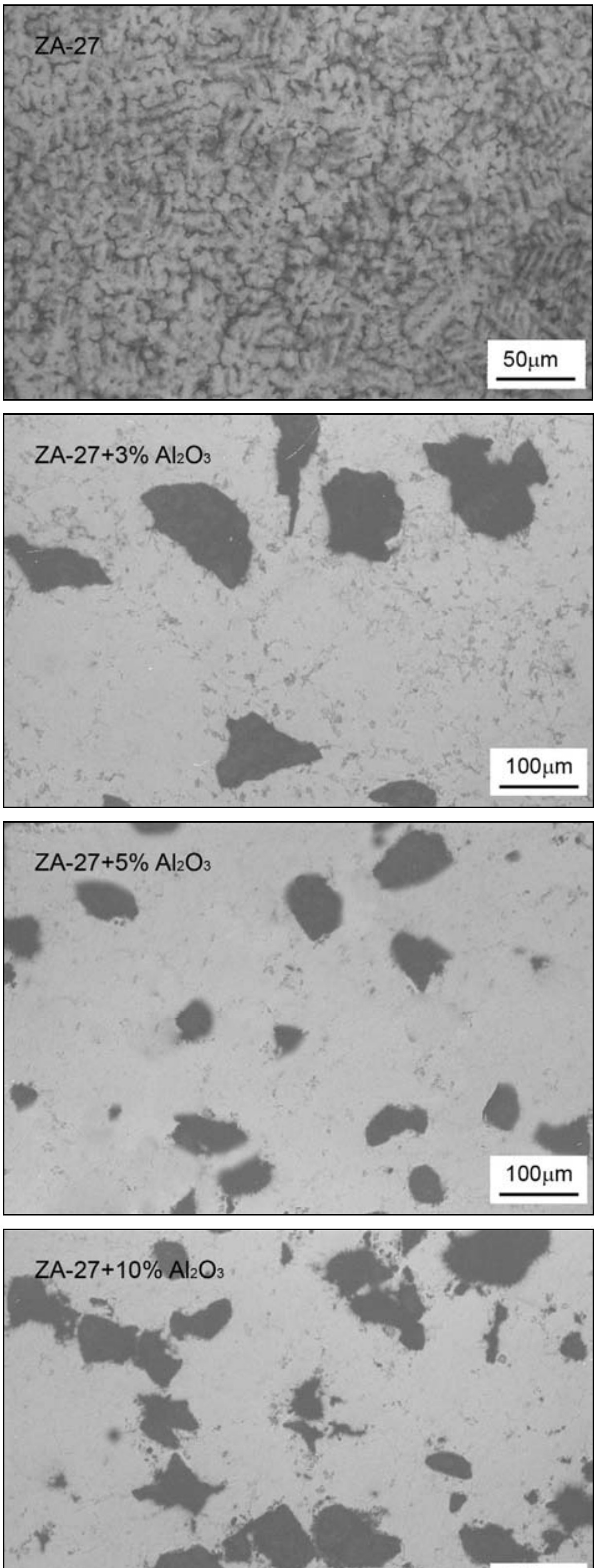


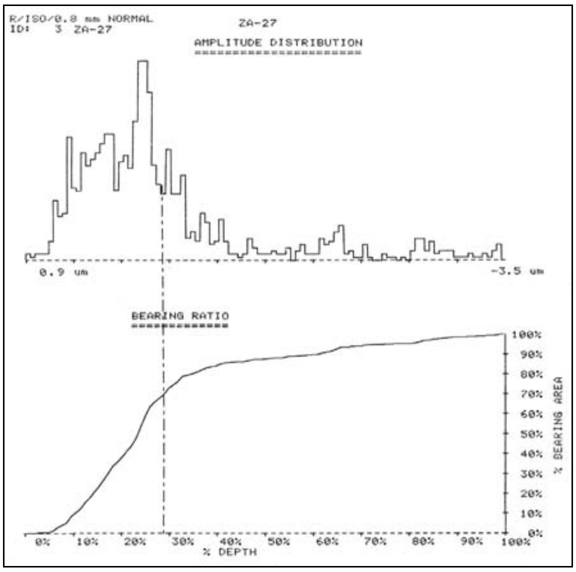
Figure 1. Microstructure of ZA-27+Al_2O_3 composite

The structure of the Za-27 alloy sample, obtained by the steel case casting is typically dendritic. The small graininess of the dendritic branches is the consequence of the thermal undercooling during the casting process. The prominent homogeneity of the dendritic structure is also noticeable, that points to the favourable relation of mechanical properties. Additionally, the interdendritic phase rich in zinc is evenly distributed within the structure (without appearance of "islands", larger zones, etc.), what then points to the good distribution, both on the surface and within the bulk, of the crystallization centers during the solidification phase, namely it points to the properly set solidification process.

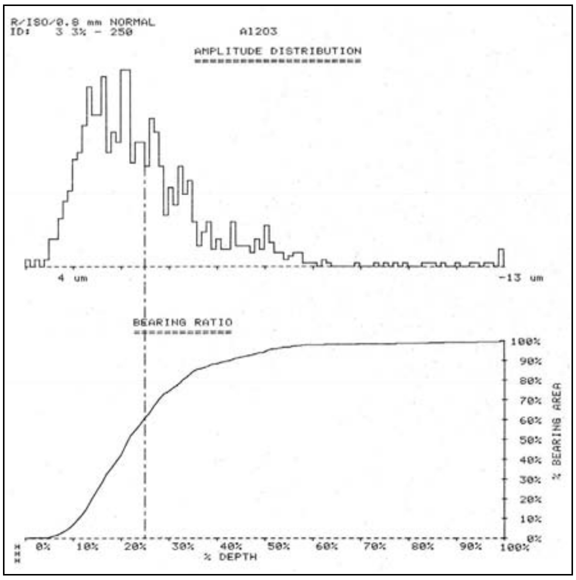
The structures of the composite samples are morphologically so similar, that there is no need to describe them individually, at least in regard to the shape of the primary particles. The fundamental reason for obtaining the morphologies presented in the photos is the change in the solidification process due to the parameters of the compocasting method. Namely, in the semi-solidified state at the temperature interval of compocasting, the Za-27 alloy melt is subjected to very slow cooling (average cooling rate of 5°C/min). If the melt was not subjected to the mixing procedure in the semi-solidified state, the structure at the room temperature consists of rough, very developed dendrites. However, due to the shear forces action during the compocasting procedure, the large, elliptic primary particles were formed as large grains. In other words, the transformation of the dendritic into the non-dendritic structure has occurred.

The distribution of the reinforcing agent points to a tendency that a lot of particles are placed in the interdendritic phase area. This is clear due to mixing of the semi-solidified melt of the alloy, which at the process temperature has a large portion of the liquid phase and low resistance to the infiltration of particles. Later, during the cooling, the particles become rounded. It is interesting that there are many particles that are placed within the primary dendrites, what points to their relatively large energy acquired from the mixer. It looks like a "knocking-in" of the particles into the dendrites.

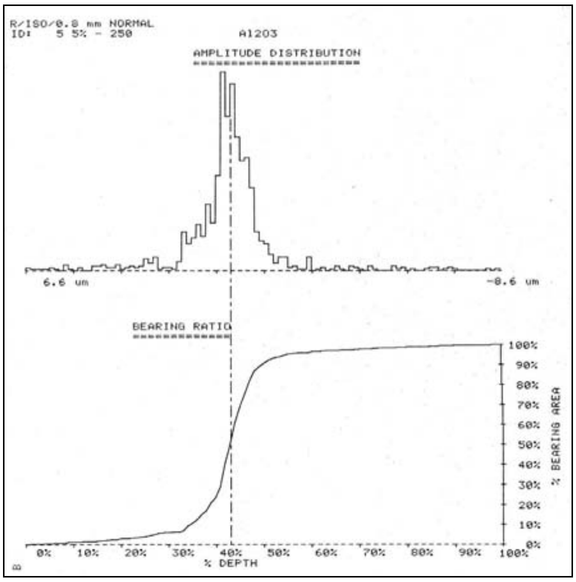
Contact surfaces microgeometry of investigated composite materials is represented in this paper by major roughness parameters (Ra, Rz, Rmax) – Table 2, and by bearing area curve, Figure 2.



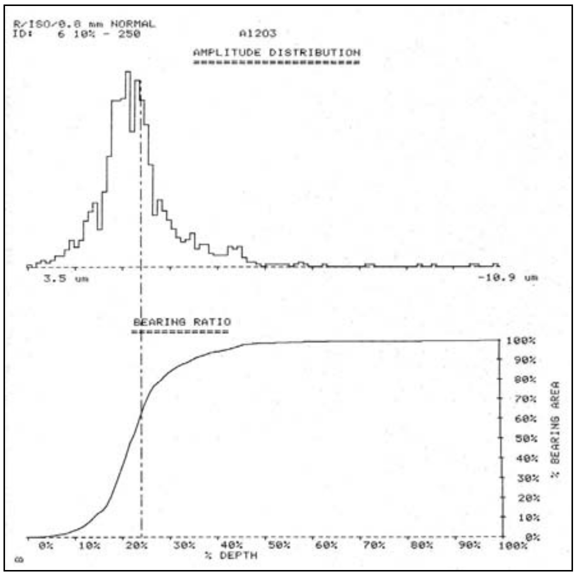
ZA-27



ZA-27+Al_2O_3 3%, 250μm



ZA-27+Al_2O_3 5%, 250μm



ZA-27+Al_2O_3 10%, 250μm

Figure 2. Bearing area curve and diagrams of amplitudes distribution for tested composites

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	250	0.83	2.39	6.03
	5	250	0.43	1.78	3.48
	10	250	0.93	3.32	6.51

Hardness of tested composite materials and ZA-27 alloy is shown in Figure 2. As anticipated, based on literature data, it can be seen that it is hard to find regularities in values of composite samples hardness during changes in mass share of particles' sizes.

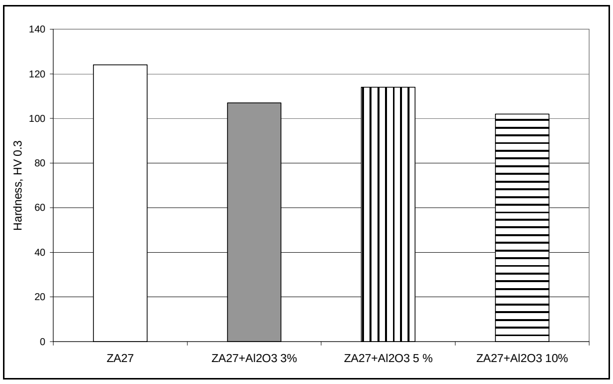


Figure 2. Hardness of ZA-27+Al_2O_3 composite samples

2.2 Tribological investigations

Tribological investigations are realised with ball-on-block nanotribometer (Figure 3.) without lubrication at room temperature environment.

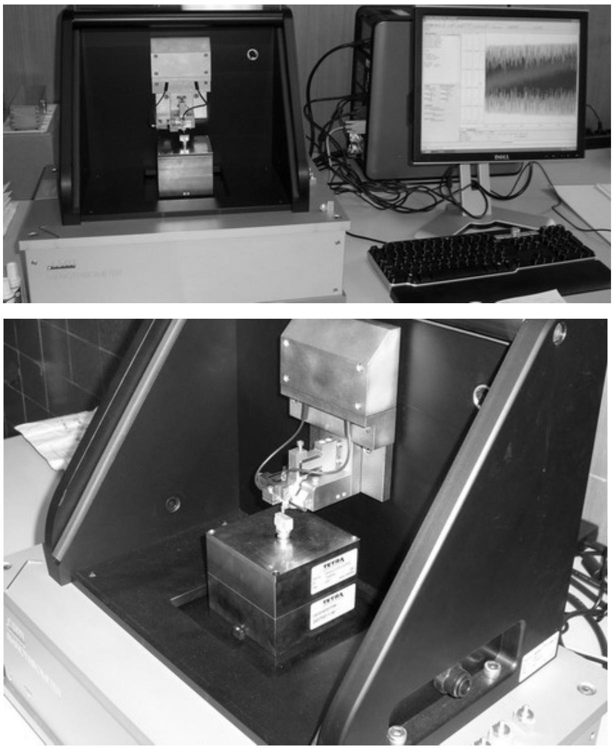


Figure 3. Ball-on-block nanotribometer

Tests are realised with linear reciprocating nanotribometer module. Contact pair consists of the steel ball of Db=1.5 mm diameter and block with bb=6.35 mm width, lb=15.75 mm length and hb=10.16 mm height. Blocks are made of ZA-27 + Al_2O_3 composites.

Testing is done with varying of four levels for normal contact loads (10 mN, 50 mN, 100 mN and 120 mN) and three levels of sliding speed (10 mm/s, 20 mm/s and 30 mm/s), with no lubrication. During tribological testing only main tribological parameter was recorded - normal force / friction coefficient.

3. RESULTS OF TRIBOLOGICAL INVESTIGATION

Based on realised tribological investigations, diagrams of friction coefficients vs. testing conditions are made – Figures 4. to Figure 7. Diagrams show existence of significant influence of contact conditions parameters (v and Fn) on frictional behaviour of all tested contact pairs. For all tested materials similar trends of these influences is present, only at different levels. With increase of sliding speed and normal contact load friction coefficient increases.

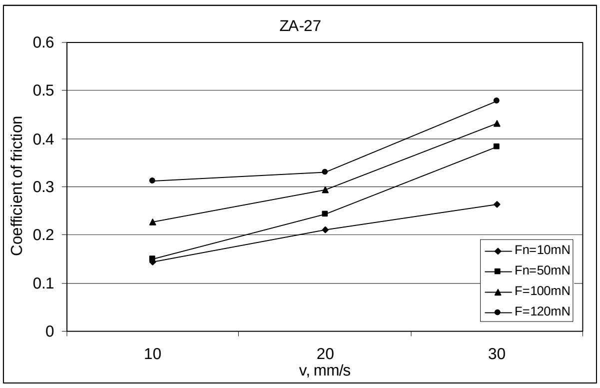


Figure 4. Friction coefficient, ZA-27

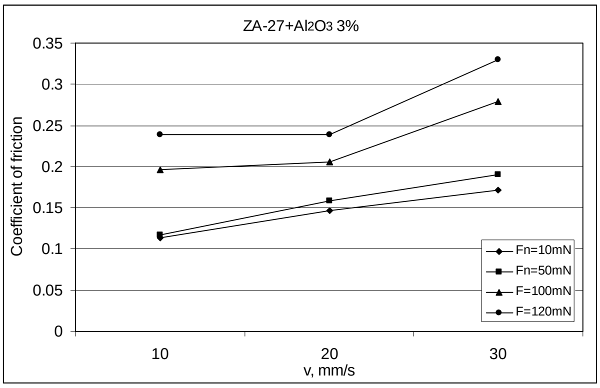


Figure 5. Friction coefficient, ZA-27+Al_2O_3 3%

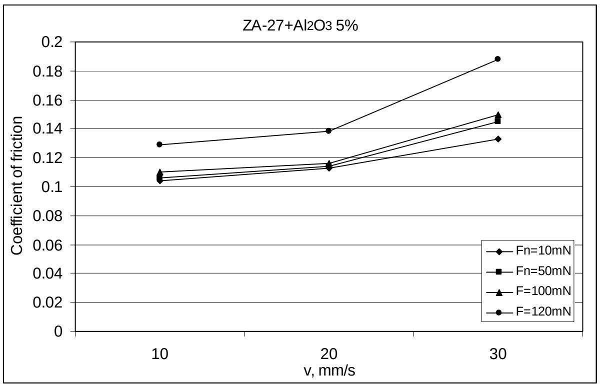


Figure 6. Friction coefficient, ZA-27+Al_2O_3 5%

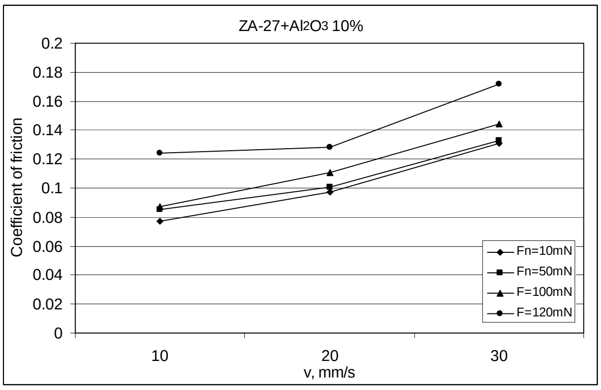


Figure 7. Friction coefficient, ZA-27+Al_2O_3 10%

Contact parameters influence (sliding speed and normal contact load) on friction coefficient can be given by analytical dependencies (regression function) as:

$$f=C \cdot Fn_x \cdot v_y$$

C constants and x and y exponents with correlation coefficients are given in Table 3.

Tabela 3. Friction coefficient

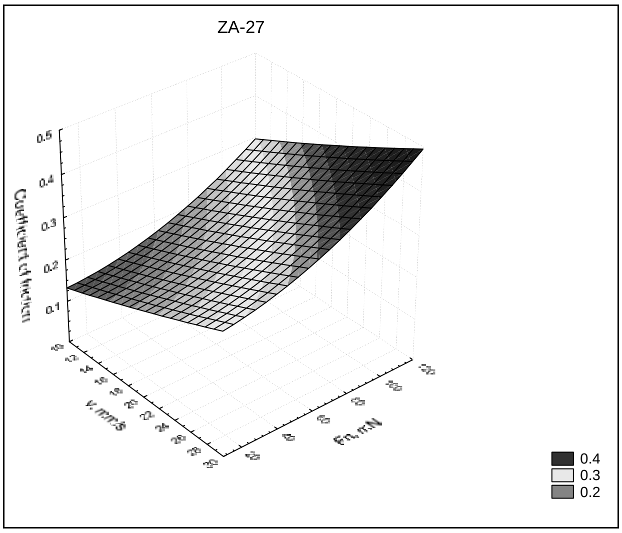
Friction coefficient $f=C \cdot Fn^x \cdot v^y$		C	x	y
ZA-27		0.0189	0.2642	0.5705
Reinforcer	Al_2O_3 3%	0.0237	0.2760	0.3450
	Al_2O_3 5%	0.0391	0.0825	0.2951
	Al_2O_3 10%	0.0229	0.1034	0.4107

Obtained analytical dependencies points clearly to previously presented relations of frictional characteristics of contact pairs.

In order to perceive the influence of sliding speed and normal contact load to friction coefficient of ZA-27 alloy and composite materials based on ZA-27 alloy reinforced by Al_2O_3 particles, 3D diagrams are made that show dependencies of friction coefficients to sliding speeds and normal contact loads. These diagrams are shown in Figure 8.

Graphic relations of friction coefficients change with sliding speed and normal contact load are approximated by exponential regression functions.

The least influence of sliding speed and normal contact load change on friction coefficient change is recorded for composites with larger mass share of Al_2O_3 particles (5 and 10 mas.%).



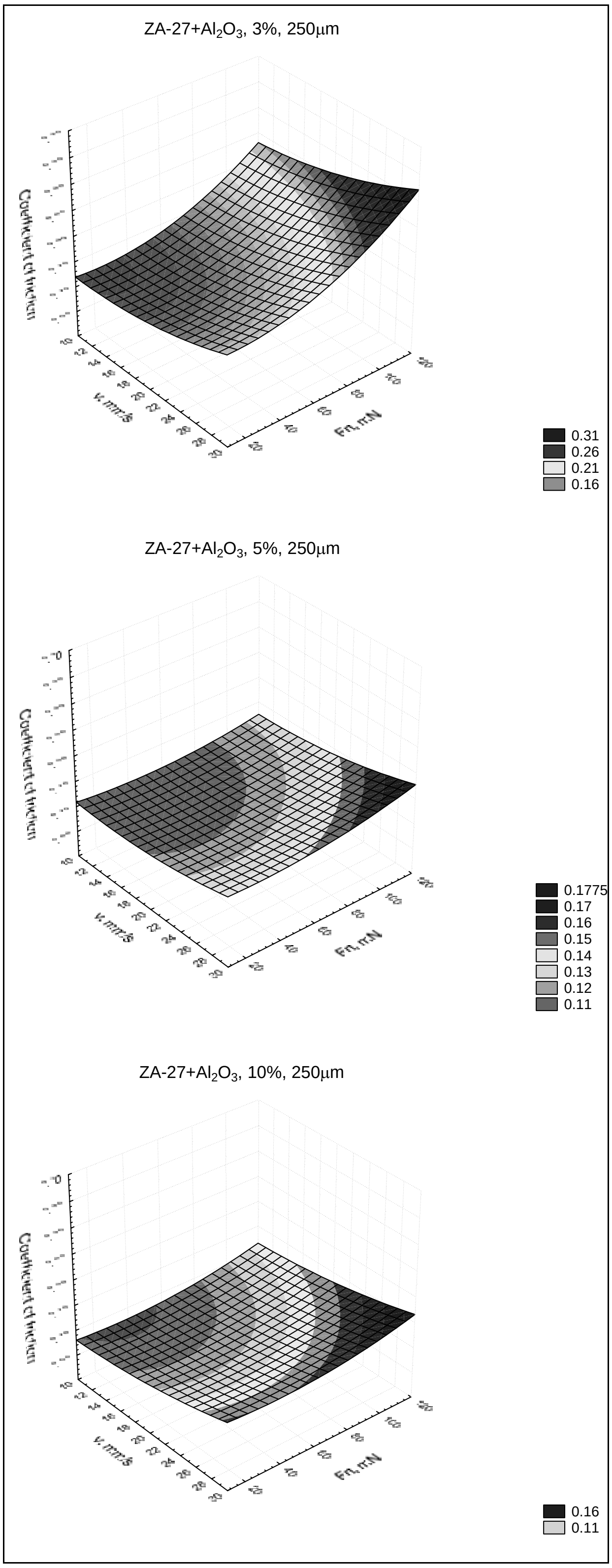


Figure 8. Friction coefficient, ZA-27+Al_2O_3

Comparative representation of friction coefficients level of composite materials for different contact conditions are given in Figure 9. It clearly indicates the level of frictional characteristics for tested materials.

Showed diagrams give unique influence of normal contact load on friction coefficient for all tested materials. Generally, friction coefficient rises with sliding speed and normal load increase. Differences in friction coefficient levels for tested materials for all conditions have the same character.

The largest values of friction coefficient are for the highest sliding speed (v=30 mm/s) and for the highest normal load (Fn=120 mN). For the smallest sliding speed value (v=10 mm/s) the smallest values of friction coefficient are recorded for all tested samples.

Increase of mass share of reinforcing Al_2O_3 particles positively influence frictional characteristics. This is especially the case when higher sliding speed and higher normal loads are applied, when it is possible to lower the friction coefficient up to 60% compared to raw material basis (ZA-27 alloy) by increase of reinforcing Al_2O_3 particles mass share.

It can be noticed that for all testing conditions the best frictional characteristics is obtained for composite material with Al_2O_3 particles of 250 μm sizes and in quantity of 10 mas.%.

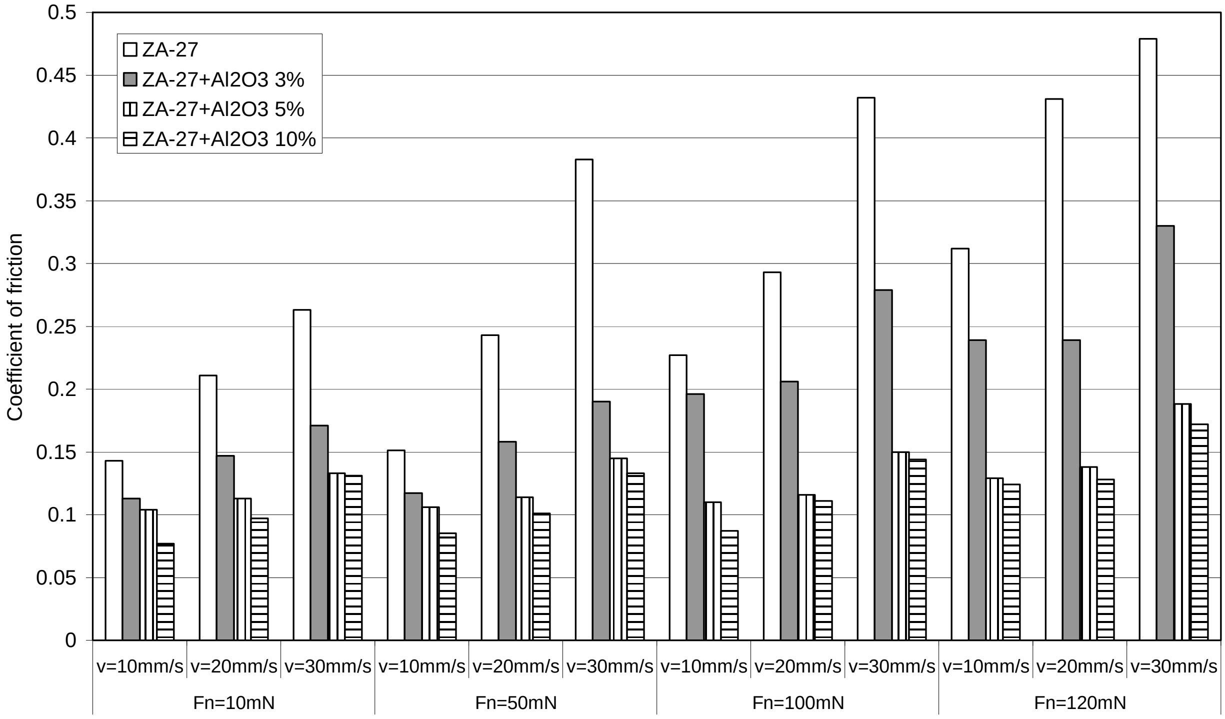


Figure 9. Friction coefficient, ZA-27+Al_2O_3 vs. sliding speed and normal load

4. CONCLUSIONS

Experimental results show that it is possible to influence the tribological characteristics of tested composites based on ZA-27 alloy, by changing of reinforcing Al_2O_3 particles mass share.

According to investigation of tribological characteristics of tested composites based on ZA-27 alloy, reinforced by Al_2O_3 particles, following conclusions can be drawn:

- All tested composites samples have significantly lower friction coefficient compared to ZA-27 alloy basis for all testing conditions.
- Increase of reinforcing Al_2O_3 particles mass share positively influence frictional characteristics. This is especially expressed for higher sliding speeds and higher normal loads.
- The best frictional characteristics are recorded for composites with the highest Al_2O_3 particles mass share of 10 mas.%.

ACKNOWLEDGEMENT

The results of this paper are realized through the national project TR–14005 financially supported by the Ministry of Science of the Republic of Serbia.

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