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# Influence of Organic Coating Macrostructure on its Resistance to Erosive Wear

D. Kotnarowska

*Radom Technical University, Faculty of Mechanical Engineering,  
Institute of Vehicles and Machines Maintenance, al. Chrobrego 45,  
Radom 26-600, Poland, [danutakotnarowska@op.pl](mailto:danutakotnarowska@op.pl)*

## Abstract

The paper describes an influence of polymeric (epoxy) coating composition on coatings intensity of wear resulting from hard particles of granulated alundum impacts. It was stated experimentally that introduction of fillers to interlayer of epoxy coating influenced advantageously the coating resistance to alundum particles impacts. It was found too, that the angle of impact smaller the coating wear intensity higher. Moreover, with extending of coating thickness coating wear decreased. It should be explained by the fact that impacting particle energy, released in coating – erosive particle tribological system, is more effectively suppressed by the coating of bigger volume.

**Keywords:** intensity of erosive wear, epoxy coating, glass microspheres.

## 1. Introduction

Processes of erosive wear of machine elements with protective organic coatings are different from wear processes characteristic for machine elements without such kinds of coatings. From qualitative point of view the wear process of machine elements – with or without coatings – are similar because in both cases intensity of erosive wear depends on inclination angle of element in relation to erosive particles flux. But

on quantitative score parameters of erosive wear (intensity of wear, type of loss in element surface) are significantly different because of different mechanism of these materials (organic and metallic) wear. In case of steel the material destruction is first of all connected with impact–abrasive nature of influence of hard particles impacting on machine element surface [1,2]. However, destruction of polymeric material is caused mainly by microcutting with hard abrasive particles [3,4,5]. In this connection values of glancing angle of maximum wear speed are different for steel and for polymers. For steel such values are close to  $45^\circ$  [1,2] and for polymeric material of high elasticity are equal  $5\text{--}10^\circ$ . Starting from  $45^\circ$  wear becomes stabilized and for glancing angles of value  $60^\circ < \alpha < 85^\circ$  practically does not depend on glancing angle of erosive particles [6]. This is very important feature that allows predicting which machine elements will be exposed to intensive erosive wear and how to protect them with coatings.

Organic coatings are broadly applied as protective topcoats for technical devices. During their service life they are frequently exposed to corrosion as well as to mechanical influences. In many cases, mechanical failure contributes to more intensive corrosive wear. Erosive wear of an organic coating is a form of mechanical wear. This type of damage is typical for organic coatings applied to agricultural and building machinery, i.e. subjected to erosion caused by sand, stones or lumps of soil.

The process of damage resulting from an impact of tiny solid or liquid particles against the surface of a coating, combined with the loss of its thickness (i.e. mass loss) is called erosive wear of an organic coating. The most important factors influencing erosive wear of an organic coating are: the friction coefficient between erosive particles and the coating, the velocity of erosive particles and an angle  $\alpha$  between the direction of an impact of erosive particles and the surface of the coating [1–5,7].

The type of reaction between an erosive particle and the surface of the organic coating, i.e. reaction with slip or with microcutting, depends on the value of the impact angle ( $\alpha$ ) and velocity of an erosive particle ( $v$ ) at the time of impact. Plastic strains of the coating are of minor

value if residual stresses generated by the collision do not exceed the limit of elasticity of a high-molecular material. Exceeding the yield point causes an increase in the plastic strain of the coating and results in the forming of micro cracks. Propagation of micro cracks and their junctions contributes to chipping of the coating's components (fillers, pigments and high-molecular material) [8–16].

An improvement in resistance to erosive wear of an organic coating can be achieved by modification of the composition of the coating with various types of inorganic fillers (in the shape of carbon or glass fibres, glass balls or microspheres) or with metallic fillers (e.g. flakes of aluminium or zinc) [17–25]. The fillers mentioned above influence changes in the mechanical properties of the coating, such as hardness, tensile and tear strength, unit elongation and friction coefficient. It is well known that erosive wear depends on those factors [1,16,17,18,24]. The type of erosion predominating under set conditions, i.e. deformational erosion or shearing erosion, depends on the value of the impact angle  $\alpha$  of the erosive particle. For an angle  $\alpha < 45^\circ$  shearing erosion dominates because the force tangential to the coating's surface, causing its shearing grows with reduction in the  $\alpha$  value. An improvement in resistance to shear erosion is achieved by application of a high-hardness coating material [1,12].

For a frictional system consisting of a high-molecular material and an erosive particle an increase in the friction coefficient is observed when plastic deformation of the element made from a high-molecular surface increases [2]. It affects the course of the characteristic of erosive wear, i.e. its maximum moves into the direction of smaller  $\alpha$  values [2].

As a result of the striking of erosive particles against the surface of the polymer material, roughness of this surface increases, sometimes even several times [5,14]. Various types of fillers improve the resistance of a polymer material to erosive wear. For example, the wear of polyamide PA6 modified with carbon fibres is four times lower than for the unmodified one [3]. Moreover, high resistance to erosive wear also reveals also following materials: polyurethane elastomers, fluorine

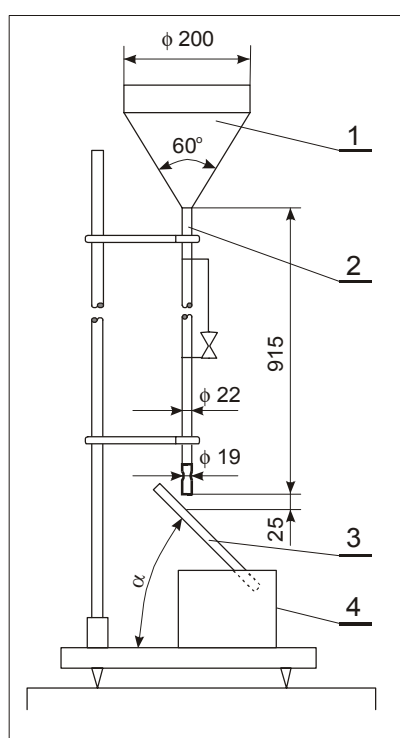
plastics, high-molecular plastics modified with glass fibres, plastics filled with quartz fibres [4,5].

## 2. Experimental

### 2.1. The examination method of erosive wear of an epoxy coating

The examination method of erosive wear of an epoxy coating employing the testing device (see Fig. 1), recommended by the Polish Standard PN-76/C-81516, was used.

a)



b)

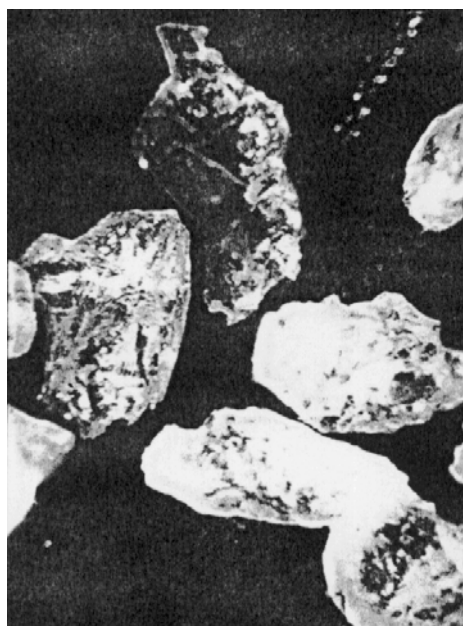


Fig. 1. a) Apparatus for testing erosive wear of organic coatings:

1. Container for erosive material, 2. Pipe transporting erosive material, 3. Rotational holder for fixing metallic test specimen with an organic coating, 4. Container collecting erosive material after the test.

b) Particles of granulated alundum (magnification 50 times)

In order to learn the influence of an impact angle of the erosive particle on the wear of an organic coating, the test specimen was mounted in a specially designed specimen holder which allowed

precise setting of the angle of the specimen's surface, which was subsequently subjected to testing. The tilt range was from 0 to 90°. Particles of granulated alundum of grain size 0.60–0.71 mm (according to the Polish Standard PN-76/M-59111) have been used as the abrasive material. Aluminium trioxide ( $\text{Al}_2\text{O}_3$ ) is the main constituent (99% by weight) of the abrasive while  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{CaO}$  and  $\text{Na}_2\text{O}$  make up its residual part. The mass of the one charge of alundum delivered to container 1 (see Fig. 1) was 3.5 kg, while at the end of the test, i.e. when the substrate material was exposed, the charge of alundum was reduced to 0.5 kg. In order to assess the resistance of the coating to erosive wear I-criterion, calculated from Eq. (1), was used.

$$I = \frac{G}{M} \quad (1)$$

where  $I$  is the intensity of erosive wear of organic coating ( $\mu\text{m} / \text{kg}$ ),  $G$  is the coating thickness ( $\mu\text{m}$ ) and  $M$  is the mass of erosive particles (kg).

The above formula displays the ratio of the coating thickness to the total mass of erosive particles producing the total wear of the coating within the tested area, i.e. generating the exposure of the substrate material in the elliptic shape of the minor diameter of  $d = 3.6 \pm 0,1$  mm.

## 2.2. Preparation of an epoxy coating

The first type of the coating examined consisted of three layers of the epoxy. The second type of coating consisted of three layers of the epoxy with the composite interlayer [23] containing 10 wt % of glass microspheres (see Figs. 2 and 3) of diameter of  $\phi < 30 \mu\text{m}$  [25]. The third type of coating consisted of three composite layers. All three types of coating were produced on steel test plates.

The epoxy coatings subjected to the wear resistance tests were prepared from red oxide epoxy paint which is resistant to chemicals. This paint was blended with a polyamide curing agent at the mass ratio 77:23, respectively. In the case of a modified coating, filler in the form of glass microspheres was added into the mixture. Then, 30 min

mixing was performed and after a period of two 2 h the production of coatings began. Three layers were deposited consecutively by means of air-operated spraying. Each layer was subjected to a two-stage hardening for 24 h at a temperature of  $20 \pm 2^{\circ}\text{C}$  and then for 30 min at a temperature of  $120^{\circ}\text{C}$ . Before the testing procedure was performed all the specimens were subjected to 10 days acclimatisation at a temperature of  $20 \pm 2^{\circ}\text{C}$  and at a relative humidity of  $65 \pm 5\%$ .

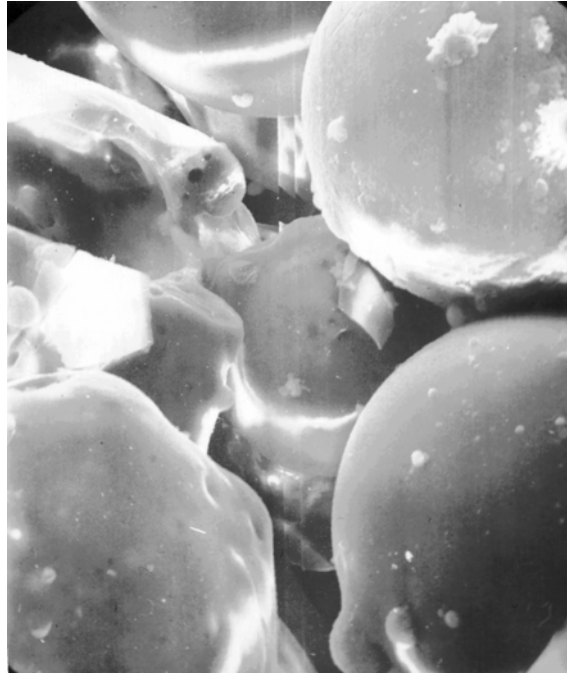


Fig. 2. Morphology of glass microspheres (magnification 2000 times)

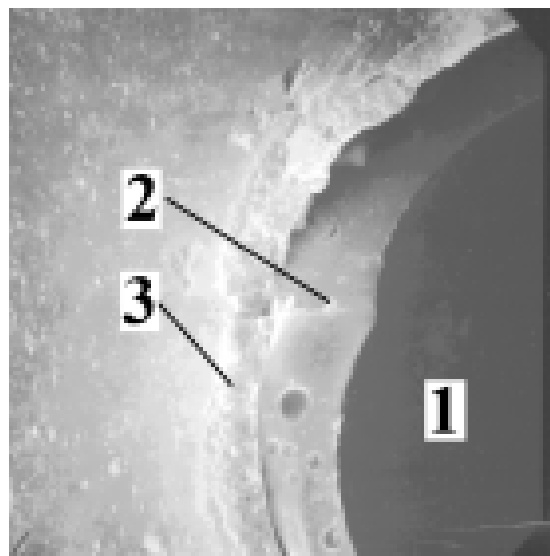


Fig. 3. Cross-section of a glass microsphere (magnification 4000 times): 1. Inside of the glass microsphere, 2. Wall of the glass microsphere, 3. Polymer finish

The thickness measurements of the coating were performed by means of an electromagnetic thickness gauge (A-52) and the average thickness of the three-layer coating was 120  $\mu\text{m}$  (Fig. 4). During examination of coating thickness influence on its erosive wear intensity the thickness of coatings varied from 90 to 199  $\mu\text{m}$  (Fig. 6).

Glass microspheres used as filler are spherical particles of aluminosilicate filled with carbon dioxide  $\text{CO}_2$  and nitrogen  $\text{N}_2$ . The main constituents of their wall are silicon dioxide  $\text{SiO}_2$  (49–61%) and aluminium trioxide  $\text{Al}_2\text{O}_3$  (26–30%). Production of glass microspheres is based on fly-ashes which are by-products of burning hard coal in power plants.

Well developed surfaces of the glass microspheres as well as coating their surfaces with a specially invented polymer finish, composed of methyl methacrylate and methacrylic acid [25], ensure strong and tight binding of the filler and the epoxy plastic. Differentiated diameters of the glass microspheres as well as their irregular shape enable effective filling of internal voids in the structure of the epoxy plastic, which yields lower porosity of the coating. This improves both the mechanical properties and thermal resistance of the coating. It also reduces the ability of the plastic to absorb water and aggressive agents [6].

### **3. Results and discussion**

#### **3.1. Influence of morphology of epoxy coating on resistance to erosive wear**

The organic coating consisting of three layers of composite revealed the lowest resistance to erosive wear (see Fig. 4).

It is worth noting that the low resistance of the walls of the glass microspheres to shear stresses is responsible for this effect. The epoxy coating with the composite interlayer was the most resistant to erosive wear. The reason for this effect is the dissipation of energy,

released during the collision of alundum particles with the coating by the composite interlayer. The reduction in intensity of mass loss of the organic coating with the composite interlayer may be due to erosive wear products accumulation on the insides of the spherical caps of the glass microspheres.

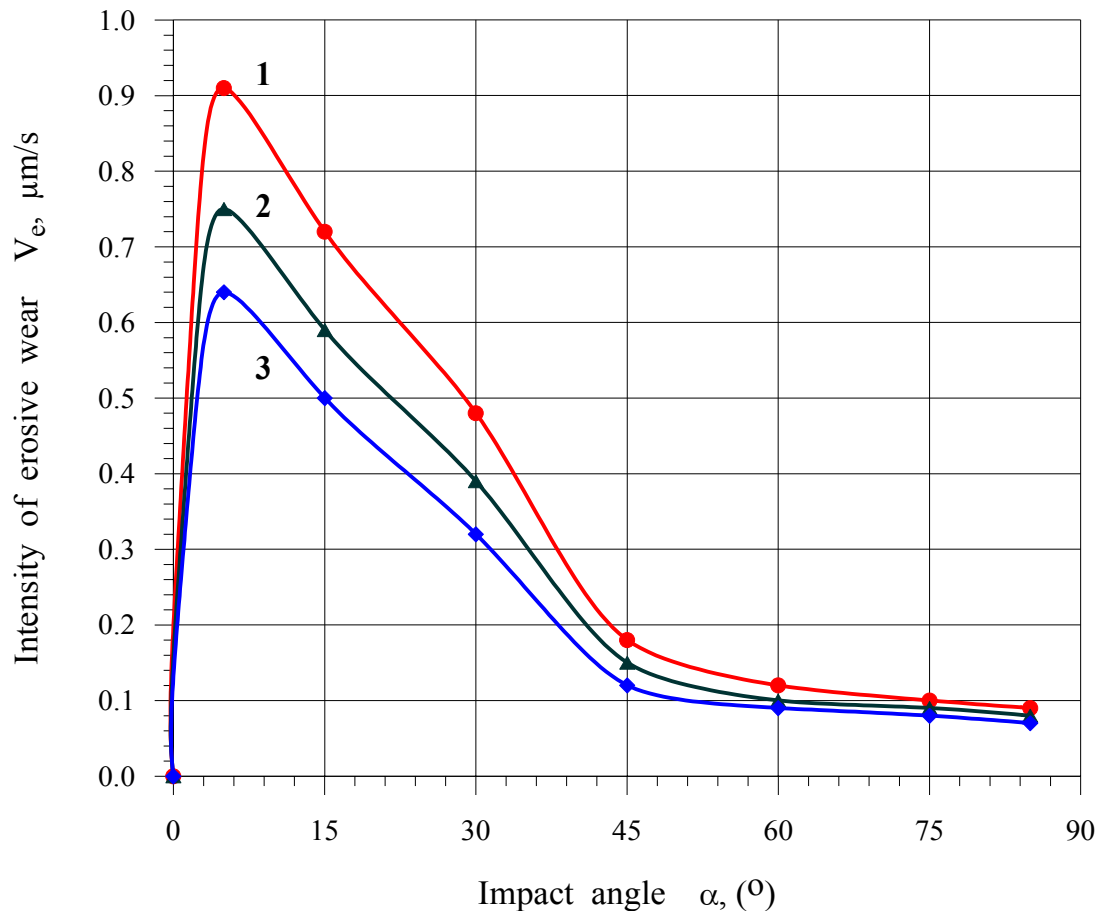


Fig. 4. Influence of epoxy coating composition on intensity of wear resulting from alundum particles impacts:

- 1 – three-layer epoxy coating modified with glass microspheres (composite coating),
- 2 – three-layer epoxy coating,
- 3 – three-layer epoxy coating with composite interlayer

### 3.2. Influence of an impact angle of alundum particles on erosive wear of an epoxy coating

The process of erosive wear of an organic coating was investigated for the values of alundum particles impact angle  $\alpha$  ranging from 5 to 85°.



Close examination of these figures shows that the lower  $\alpha$  – angle, the higher the intensity of the erosive wear of a coating. The most intensive erosive wear resulting from an impact of alundum particles was recorded for the impact angles  $\alpha < 45^\circ$ , while the lowest was for the impact angle  $\alpha > 60^\circ$ .

Morphology of the surface of the epoxy coating modified with glass microspheres which was subjected to erosive wear tests at an impact angle  $\alpha = 45^\circ$  is presented in Fig. 5.

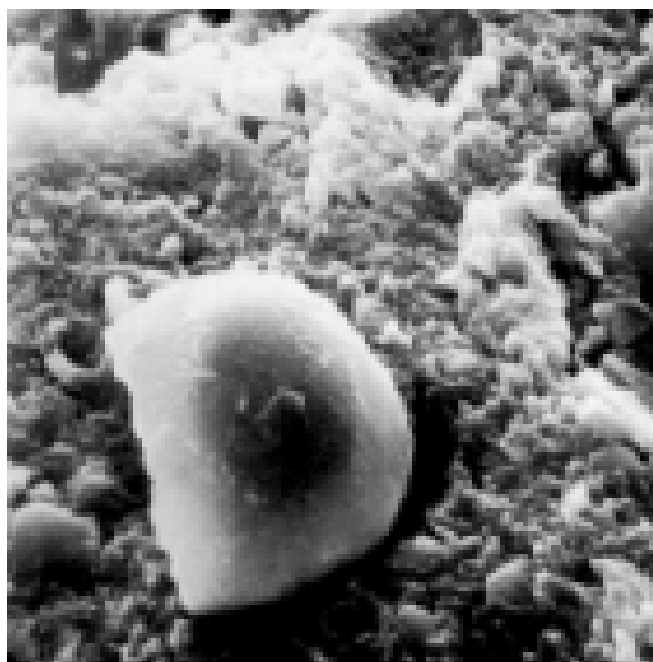


Fig. 5. Erosive wear of the surface of the epoxy coating modified with glass microspheres (magnification 1 500 times)

At the initial stage of the erosive wear of the composite coating, the walls of the glass microspheres situated at the surface of the coating are subjected to shearing, while the surface layer of the coating around the filler particles undergoes strong plastic deformation (Fig. 5). During the subsequent stages, microcutting of the epoxy material and shearing of the walls of the glass microspheres proceeds, until the steel base material appears (Fig. 6).

On the basis of carried out examination it can be stated that resistance of epoxy coating to erosive wear increases as its thickness increases

too. It means, of course, that intensity of the coating wear decreases. It should be explained by more effective dissipation of thermal energy (releasing during impacts of hard particles) by the coating of bigger thickness (volume). But increase of coating thickness over critical value leads to increase of internal stresses in the coating. It can be a reason of micro cracks generation in the coating resulting in intensity of coating erosive wear increase.

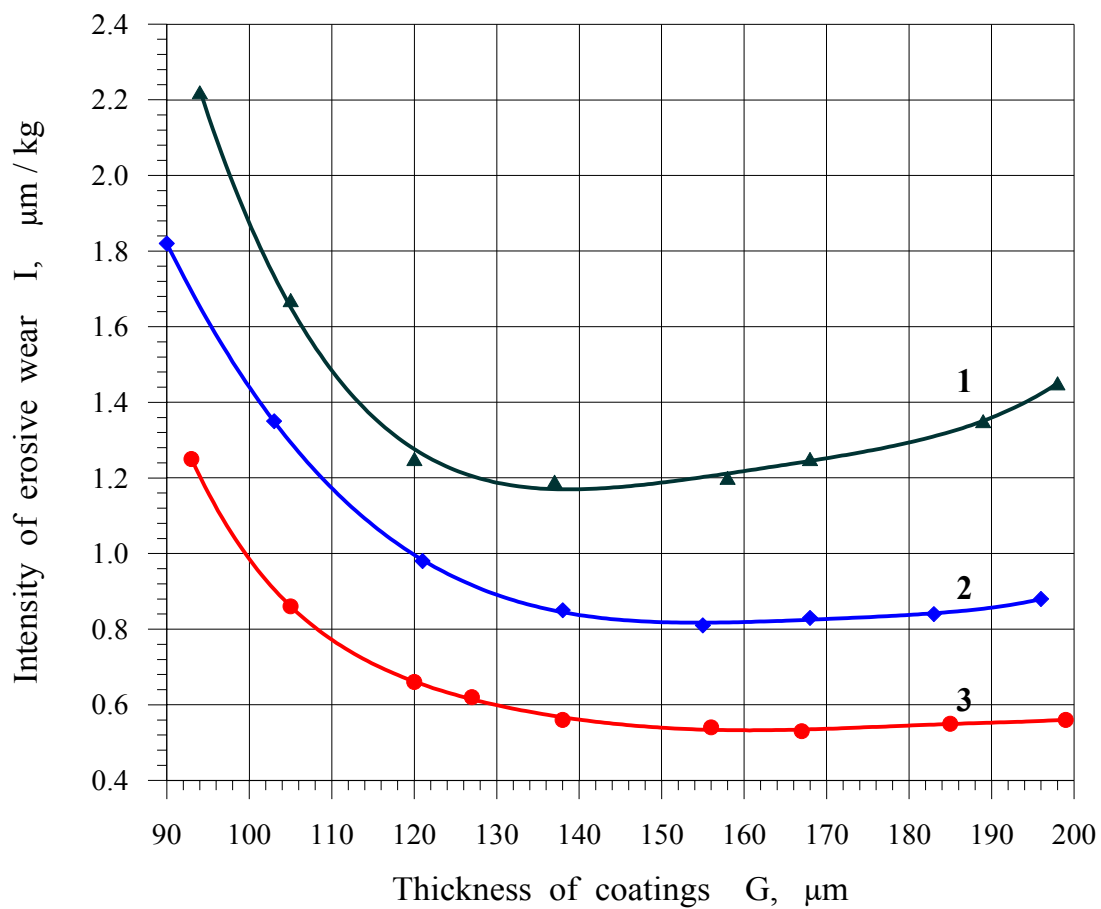


Fig. 6. Influence of coating thickness on intensity of erosive wear:

- 1 – three-layer epoxy coating modified with glass microspheres (composite coating),
- 2 – three-layer epoxy coating,
- 3 – three-layer epoxy coating with composite interlayer

## 4. Conclusions

On the basis of the examination results the following can be concluded.

The filler in the shape of glass microspheres included in the interlayer of the epoxy coating remarkably improves resistance of the coating to erosive wear generated by the action of alundum particles. It can be accounted for by the damping of energy released during the collisions between the impacting particles and the organic coating by glass microspheres. The three-layer epoxy coating, modified with glass microspheres, revealed the highest level of erosive wear, compared with the other coatings tested, because of the relatively high roughness of the surface combined with the low shear resistance of the walls of the glass microspheres.

Kinetics of wear of the coatings tested depends heavily on the impact angle  $\alpha$  of the erosive particle. For an impact angle  $\alpha < 45^\circ$  the erosion process is dominated by micro-shearing. This contributes to higher intensity of wear than in the case of an impact angle bigger than  $60^\circ$ .

Thickness of epoxy coating has an essential influence on the coating resistance to hard particles action. The thicker the coating the bigger the resistance of the coating to erosive wear because the coating of bigger thickness more effectively suppresses energy of impacting erosive particles what results in lower intensity of the coating wear.

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