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APPLICATIONS OF METALLIC COMPOSITES IN THE AUTOMOTIVE INDUSTRY AND THEIR MACHINING BY THE EDM

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Abstract

The article deals with the problems of application of aluminium matrix composites in car industry and electro discharge machining (EDM) of selected composites, which are used for engine pistons.
Composites with Al+20%Si+3%Cu+1%Mg matrix were manufacturing by the powder metallurgy route in the process of cold compaction, degassing and hot extrusion. As the reinforcing phase Al_2O_3 *particles with average size of 3, 9, 23 and 53 μm were used. Samples had constant reinforcing phase 5 and 10 % by volume. Electro discharge machining was performed using machine equipped with RLC generator. Four modes of energy of single discharge Ei in the range of 0.165 to 2.268 mJ were applied. EDM was carried out in a free – system. The main parameters determined after machining were volumetric productivity Vw (*mm^3*/min) and roughness of the machined surface expressed as Ra. It was shown that energy of single discharge influence mainly on the EDM process running. The higher was Ei, the higher were value of Vw. Increasing particle granularity from 3 to 53 μm caused decreasing in process productivity 13 to 19%. Ei affects the surface roughness during EDM. The value of Ra increases as this energy increases. When the size of reinforcing particles is growing, roughness parameter Ra is also growing.*

Keywords: *aluminium matrix composites, automotive industry, electro discharge machining, EDM productivity, surface roughness*

1. Introduction

Composites with the metallic matrix are wide group of materials, which are competitive concerning traditional metal alloys [11, 12, 14]. Such materials are important when used in a range of applications requiring lightweight, high strength, rigidity, resistance to wear [4, 5, 10, 13] etc. In order to enhance these properties and to make sure they will be maintained at high temperatures, a special reinforced (strengthened) phase is introduced into these materials with at least 15% volume share.

The reinforced phases in the metallic composites usually take form of ceramic fibres or whiskers, which are usual by oxides, carbides, nitrides, borides or other similar materials, which exhibit high level of hardness. A list of materials applied for the composite matrix is pretty long. Metals, metal alloys of Al, Ti, Cu, Mg, Fe, Ni and other can be applied. Aluminium alloys are the dominant composite matrix though, both for casting (Al-Si), for mechanical working (Al-Cu, Al-Mg) and for powder metallurgy (P/M) [12, 13, 14].

Beginning from the eighties of the XX^{th} century, the growing interest in the practical applications of composite materials can be observed, and it is particularly visible for the metallic composite applications in the automotive industry [10, 12, 14]. First meaningful application of the composite in the automotive industry is considered to take place in the Toyota Motor Co. in the year 1982 [12]. The piston of composite material for the Diesel engine has been developed and it was locally reinforced by the short Al_2O_3 fibres - it was first industrial application of the composite pressing in the fluid condition.

2. Typical composite applications in the automotive engineering

The available references present a range of metallic composite applications in the automotive engineering, both for the car body and for the engine [12, 14].
The following examples can be given:

in the engines – pistons, connecting rods, cylinder sleeves, bodies and housings, pulleys, valve seats, crankshafts, camshafts and many other,

in the other assemblies – drive shafts, shock absorber cylinders, brake disks and brake shoes, clutch plates, steering system components etc.

Typical parts of metallic composites are shown on successive drawings.

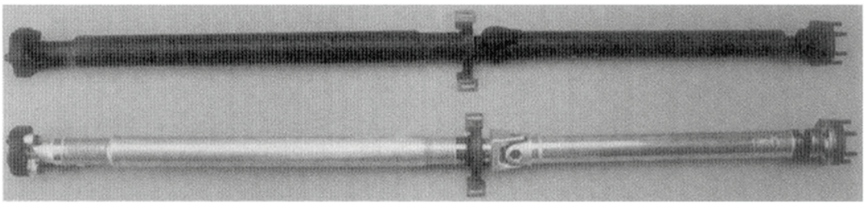

Fig. 1. Drive shaft of alumina alloy for mechanical working, reinforced by the SiC particles [12]

One of the obstacles thwarting wider implementation of the metal composites into the industrial practice are manufacturing difficulties connected with their forming and finishing. It is a result of the imperfect methods adopted for forming parts of the composite materials, which do not guarantee the required accuracy (which is often a problem of attaining the final geometry), the surface roughness and proper features of the superficial layer (SL), particularly for the important matching surfaces (interacting with the other surfaces).

The manufacturing process utilizing the parts of such material should include machining which is quite difficult because of the presence of hard-to-cut ceramic particles [3, 6, 7, 9].

In such circumstances, it is necessary to apply the tools of ultra-hard materials for the edges of the cutting tools (cemented carbides, polycrystalline diamond (PCD), cubic boron nitride (CBN) and others which adds to machining problems and the manufacturing cost.

In many countries of the world (Germany, Japan, USA, France, United Kingdom, Russia) there is extensive research concentrated on looking for the effective machining methods aimed at lowering the manufacturing cost and meeting requirements as to dimensional accuracy and surface integrity.

Fig. 2. Piston made by Toyota Inc. with the metallic composite inserts [12]

Fig. 3. Cylinder sleeve of metal composite for the engine of the Porsche Boxster automobile [14]

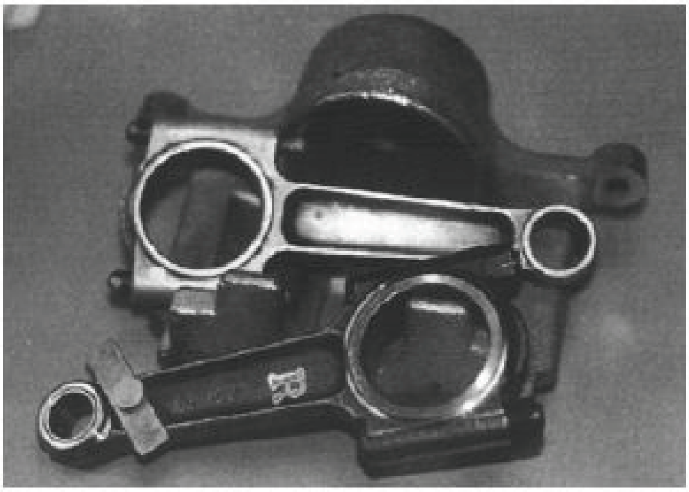

Fig. 4. Connecting rods of metal composite [12]

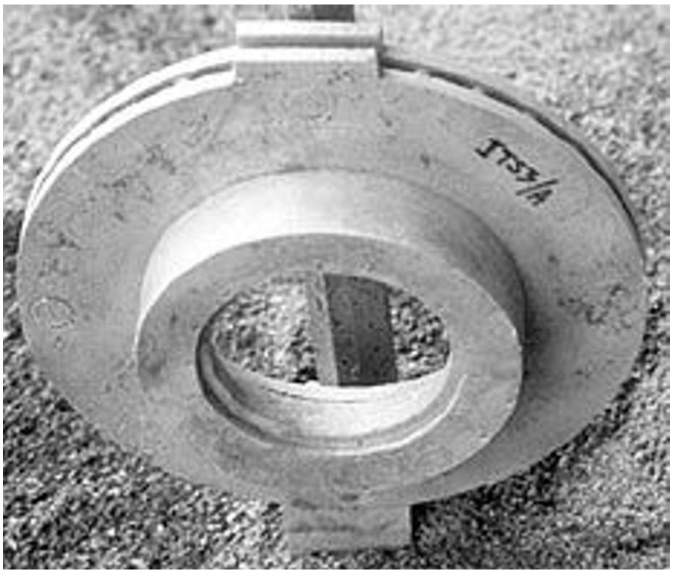

Fig. 5. Ventilated brake disks of metal composite cast at Starachowice foundry [14]

The Electrical Discharge Machining with all available variants (EDM, WEDM, μEDM, REDM, etc.) is one of the methods for shaping the parts of composites with metallic matrix and thus lowering the manufacturing cost [1, 2, 8] (while compared to other applicable methods). Nowadays, it is possible to obtain accuracy level up to 0.1-2 μm and the lustrous surface while the involved cost will be considerably lower when compared to other machining methods.

3. Composite materials used in research

The material examined in the experiments was a composite produced by powder metallurgy, whose matrix was made of an atomized alloy powder of the composition: Al+20%Si+3%Cu+1%Mg. The reinforcing phase was an Al_2O_3 powder with an average grain size of 3, 9, 23, 53 μm. The percentage content of the Al_2O_3 powder was 0, 5, 10 % by volume.

The production of the composite included the stages:

- mixing the weighed amounts of the matrix and reinforcing phase powders,
- cold-pressing of the samples under a pressure of 150 MPa,
- heating of the shaped samples at a temperature of 400°C combined with their degassing in the atmosphere of a flowing nitrogen,
- hot extrusion of bars at temperature of 420°C and at reduction ratio of 20:1.

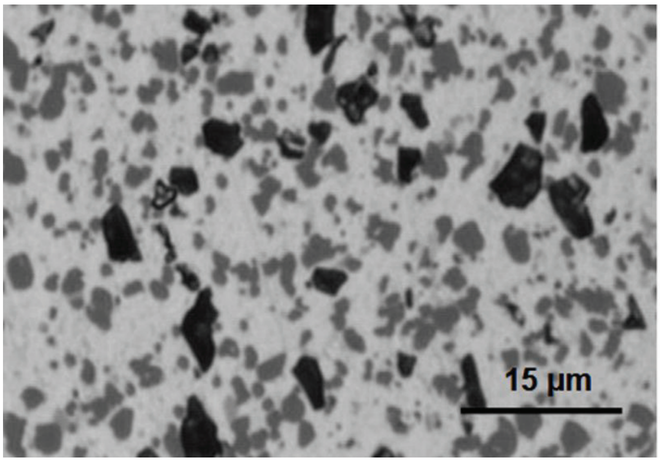

Fig. 6. Microstructure of the composite KZ-1 (5% Al_2O_3)

Fig. 6 is a photograph of a metallographic cross-section of the selected composite. The reinforcing particles (black) and silicon crystals (dark) were distributed homogeneously throughout the matrix and the densification of the material was complete, i.e. equal to 100%.

The constitution of composites used in research is given in Table 1.

Tab. 1. Code and composition of composite materials

Code of materials	**M**	**KZ-1**	**KZ-2**	**KZ-3**	**KZ-4**	**KZ-5**
Matrix	Al – 20%, Si – 3%, Cu – 1% Mg					
Reinforcing chase Al_2O_3, %	0	5	10	10	10	10
Reinforcing granularity, μm	-	9	3	9	23	53

4. Electro discharge machining (EDM)

The electro discharge machining was performed using machine equipped with RLC generator. This machine permitted controlling the process parameters within a wide range. The supply voltage U_o of the generator was 240 V, and the average operating voltage U_r was 180 V [1, 2].
Cosmetic kerosene was used as dielectric, whereas the working electrodes were made of electrolytic copper M1E.

The value of energy of the single discharge (impulse) Ei between working electrode and machined material was set down taking into account of the existing current conditions and the RLC generator parameters. The values of Ei used in experiments are shown on Table 2.

Tab. 2. Energy of the single discharge at EDM

Code	**Ei1**	**Ei2**	**Ei3**	**Ei4**
Energy Ei, mJ	2.268	1.555	0.365	0.165

The experimental set-up used for EDM was shown in early publication of authors [9]. The machining was carried out in a free system, i.e. the diameter of the working electrode exceeded the diameter of the composite sample being machined.
The parameters determined after the machining included:

- average volumetric productivity of the process *Vw* [mm^3/min],
- roughness of the machined surface expressed as *Ra* and *Rz* [µm],
- morphology of the sample surface.

The surface roughness was determined using a Taylor Hobson-10 profilograph.

5. Results of tests

The established dependence of the EDM process productivity as a function of energy of discharges is shown on Figure 7. It can be concluded from this figure, that the machining productivity greatly depends on the energy of single discharges. According to the expectations, the highest of machining capacity was recorded for the matrix material.

Introduction of the ceramic reinforcing particles make worse the conditions of machining, that is the machining productivity *Vw* assumes lower values than those for the matrix material.
It is worth to note that the thermal and electric conductivities of the reinforcing Al_2O_3 phase are substantially lower than those of the matrix material are.

Influence of Al_2O_3 particle granularity on *Vw* is also observed – Fig 8. Growing the granularity from 3 to 53 µm influenced on decreasing *Vw* of 13-19%.

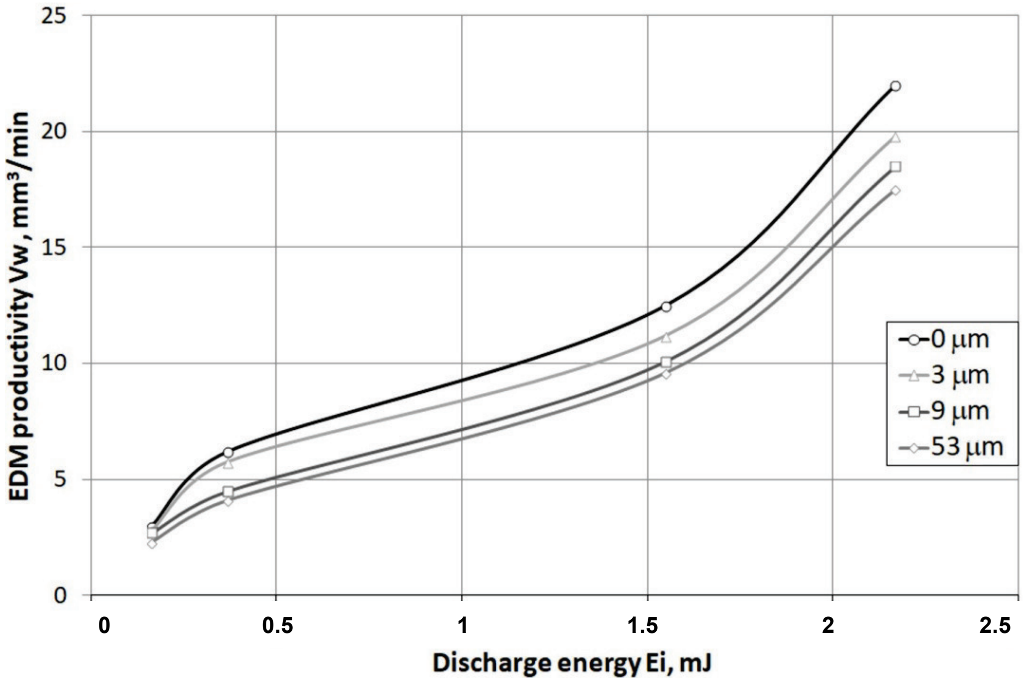

Fig. 7. The relationship between productivity of EDM process and discharge energy for matrix material M and three composites KZ-2, KZ-3 and KZ-5

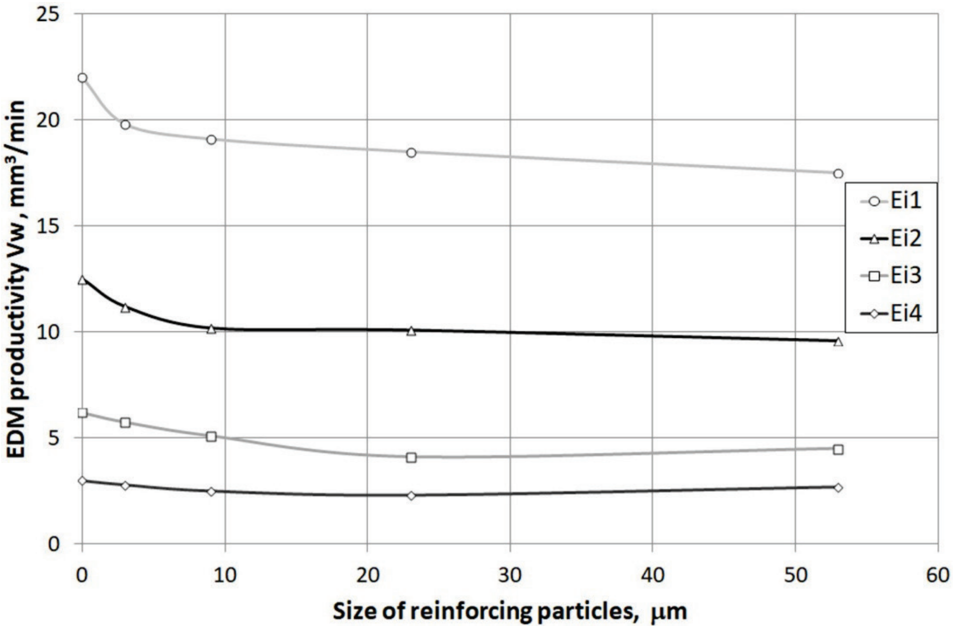

Fig. 8. Dependence of EDM productivity on granularity of reinforcing phase Al_2O_3 at different energy of single discharge Ei

On diagram – Fig. 9 – relation between EDM productivity and volume fraction of Al_2O_3 reinforcing phase (0, 5, 10 %) is presented. For each *Ei* value of *Vw* is the lower, the higher is Al_2O_3 content.

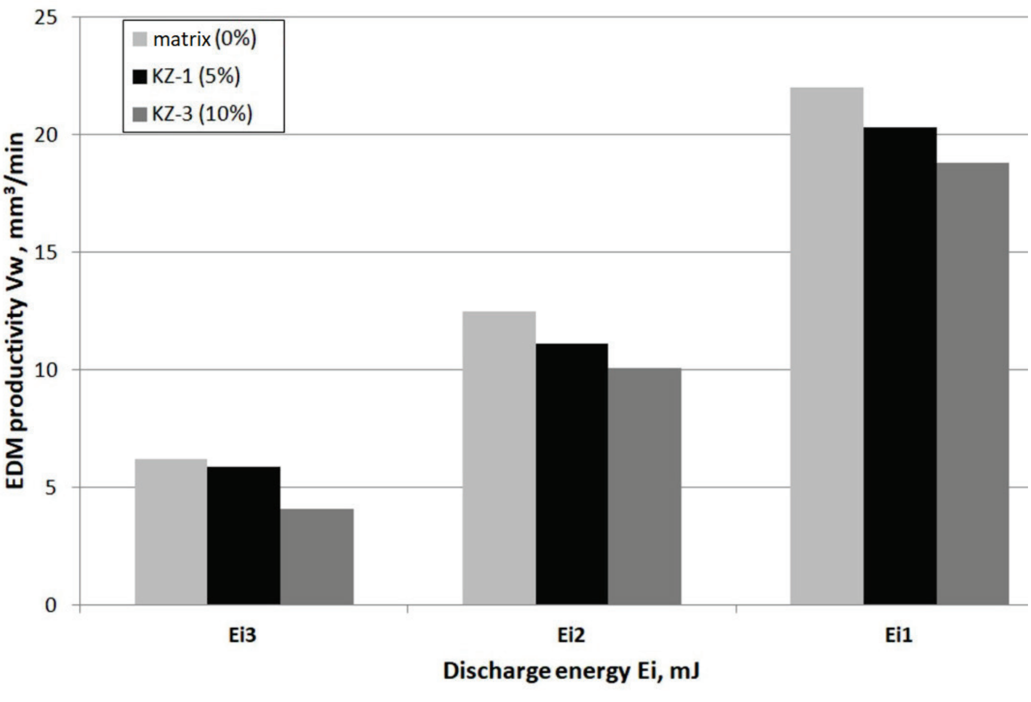

Fig. 9. Influence of Al_2O_3 content on EDM productivity Vw for selected values of discharge energy Ei

Results of roughness measuring of surface composite after EDM process are shown on Fig. 10 and 11. Moreover, SEM morphology of composites is shown on Fig. 12.

The influence of energy of discharges on the surface roughness after EDM machining of tested composites is shown on Figure 10.

The magnitude of *Ra* parameter depends also on the energy of discharges and is higher the greater is the energy *Ei*.

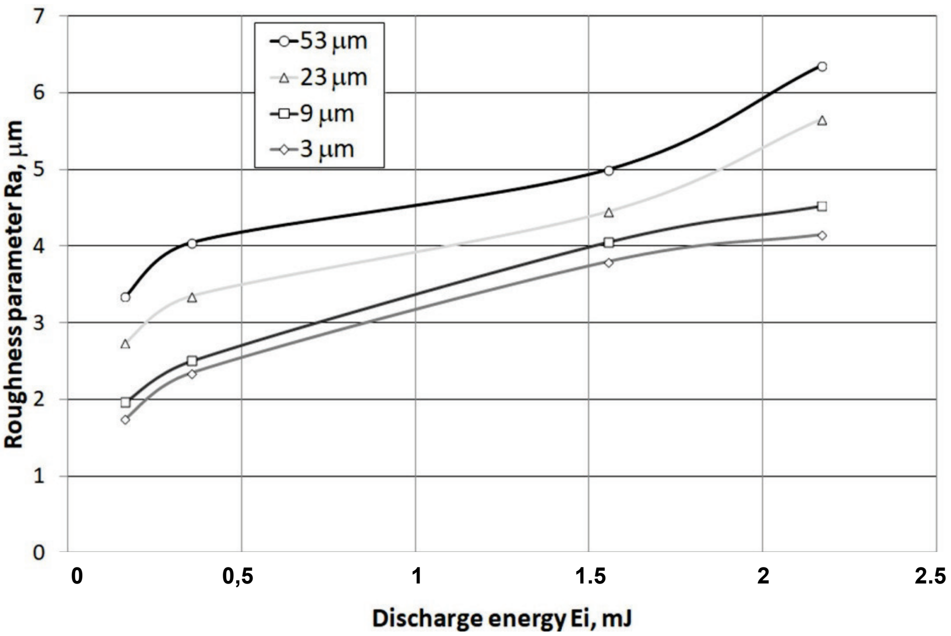

Fig. 10. Variation of the roughness parameter R_a as a function of the discharge energy applied in the EDM process of the composite materials

When the size of reinforcing particles is growing roughness parameters *Ra* is also growing – Fig. 11. This dependence is observed for all discharge energy *Ei*.

Influence of reinforcing particle size on *Ra* is not as strong as *Ei* influence.

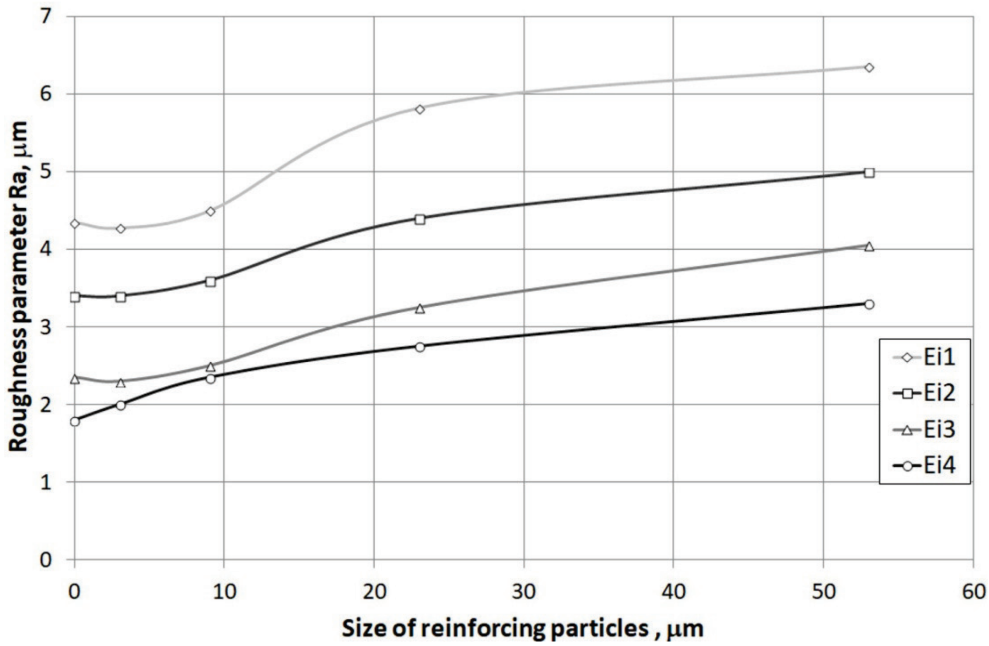

Fig. 11. SEM morphology of the composite KZ-1 after EDM at different Ei a) $0.165 \cdot 10^{-3}$ J; b) $0.365 \cdot 10^{-3}$ J; c) $2.268 \cdot 10^{-3}$ J

On Figure 12 are shown images of surfaces, obtained with a scanning type electron microscope, for KZ-1 composite having 5% Al_2O_3 reinforcing particles, after the EDM machining. Subsequent pictures 12a-12c, pertain to surfaces obtained with increased energy of the discharges.

For comparison, pictures were taken at the same magnification. As it can be seen, the surface topography undergoes significant changes with the increase of discharge energy. With the lowest energy applied being $0.165 \cdot 10^{-3}$ J – Fig. 12a – multiple, small and uniformly distributed areas of material appear on the surface of composite, which were molten during the machining. The increase of discharge energy (Fig. 12b and 12c), involves greater variety in surface topography. Molten areas have increasing dimensions; some of them take elongated forms with ball shaped endings. These are forms preceding separation of spherical erosion products [9]. It is known explained, that the characteristic feature of EDM machining effected with high energy of discharges is appearance of erosion products having shape similar to tiny balls. These balls exhibit hollow interior emerging as a result of separation, melting, vaporization and rapid cooling of material particles. Such balls are frequently not fully closed and have openings on their surface.

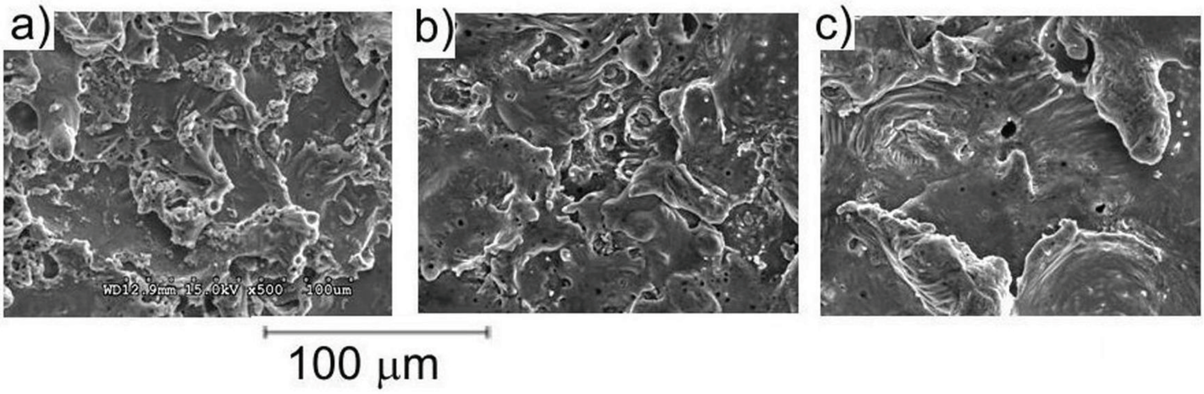

Fig. 12. Dependence of surface roughness Ra on granularity of reinforcing phase Al_2O_3 at different energy of single discharge, Ei

Beside surface images, roughness profilograms were also recorded. Such profilograms for four composite surfaces after EDM at fixed value of single discharge energy Ei1 (2.268 mJ) are shown on Fig. 13.

The following profilograms from a) to d) concerned composites with growing granularity of reinforcing particles Al_2O_3 from 3 to 53 μm. Value of *Ra* parameter changes successive: 4.24; 4.56; 5.89; 6.23 μm. These results correspond to results presented at Fig. 10 and 11.

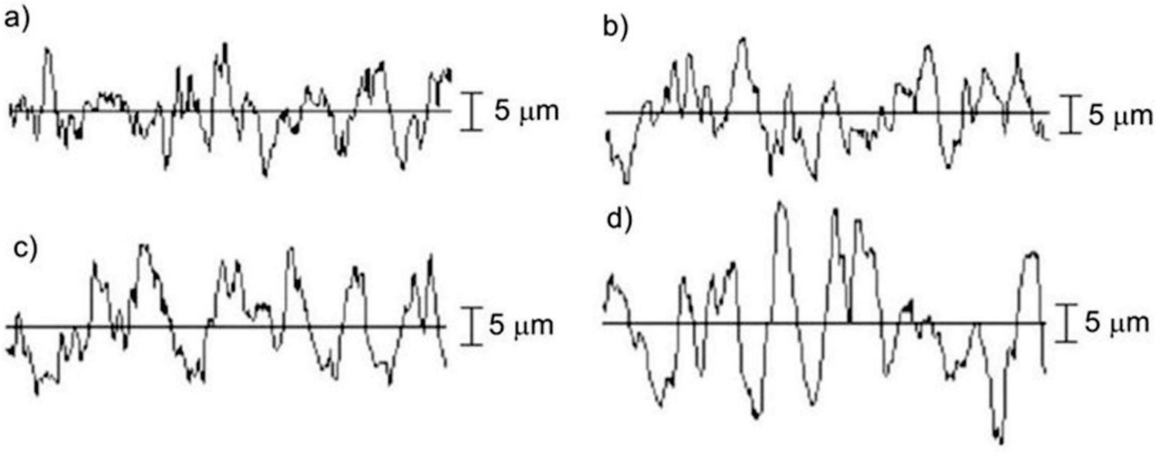

Fig. 13. Surface roughness profilograms of the composites after EDM process at discharge energy Ei 2.268 mJ a) composite KZ-2 (3 μm); b) composite KZ-3 (9 μm); c) composite KZ-4 (23 μm); d) composite KZ-5 (53 μm)

6. Conclusions

Based on conducted tests of the influence of structure of aluminium composites with Al+20%Si+3%Cu+1%Mg matrix reinforced with ceramic particles Al_2O_3 on the course and effects of electrical discharge machining, following conclusions can be formulated:

- Discharge energy Ei has an essential influence upon the productivity of the EDM machining of the composite. By appropriately selecting this energy, we can effectively conduct rough machining, semi-precise machining and finishing operations,
- EDM is more effective when applied to the matrix material than when machining the composite material,
- As the discharge energy is increased, the local erosion micro-regions become larger, thereby increasing the roughness of the surface. This effect can be seen in the SEM observations and in the recorded surface profiles.
- When the size of reinforcing particles is growing roughness parameters Ra is also growing. This dependence is observed for all discharge energy Ei. Influence of reinforcing particle size on Ra is not as strong as Ei influence.

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