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TOOL WEAR INVESTIGATION IN ELECTRIC DISCHARGE MACHINING OF ALUMINUM MATRIX COMPOSITE MATERIALS

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ABSTRACT

The objective of this work is to investigate the effect of tool diameter and pulse-on time (t_{on}) on the tool wear rate, material removal rate and surface integrity of silicon carbide hybrid aluminum matrix composites. The SODICK AD3L CNC – electrode discharge machine and the cylindrical electrode as tool were used for the proposed research. Aluminium metal matrix hybrid composite with 7% silicon carbide (SiC) was drilled by using steel electrode tool with two different diameters. Positive polarity was maintained and water – soluble dielectric fluid VITOL KS was used. Experimentally one can notice that by increasing the pulse duration the electrode wear and machining speed increase. In case of drilling deep holes with small diameters, the electrode tool wear is more pronounced and the machining speed decreases significantly.

KEYWORDS: metal matrix composites, electrical discharge machining, electrode wear, material removal rate.

1. INTRODUCTION

The electrical discharge machining (EDM) is a process of metal removal using an accurately controlled electrical discharge (spark) trough a small gap (~10-100 μm) between an electrode and a workpiece filled with dielectric fluid [1-3]. The technique allows the machining of high – strength and wear resistance materials into complicated shapes since the hardness of the workpiece has no effect on the process. EDM permits the machining to be done even after the quenching process. The machining forces are negligible compared to those met in mechanical material removal process.

Particle reinforced metal matrix composites (PRMMCs) are increasingly popular as material of choice for fabricating high – strength parts in aviation industry, automotive industry, electrotechnology, sports and recreation. At the moment, a large variety of composites are available. The matrix can be realized from metal, polymer or ceramics and reinforcement can be of similar types in form of fibres, particles or powder. The investigation described in this paper was carried out on aluminium composite material reinforced with ceramic silicon carbide (SiC) particles.

The composition and properties of the used material are given in table 1. Traditional machining of this type of composites is difficult because hard reinforcement particles induce high wear in cutting tools. Application of wear – resistant materials such as polycrystalline diamond may be limited by their prohibitive cost [4]. Intricate shapes of workpieces may also limit the applicability of traditional material removal operations.

Due to the presence of two phases with completely different properties, EDM machining of PRMMCs imposes few problems. Aluminium matrix has a low melting point and a high thermal conductivity, while the brittle reinforcement is characterized by a high melting point and low thermal conductivity. High thermal resistance of composites has an adverse effect on the efficiency of EDM processes and it is one of those aspects that require a lot of investigative efforts.

Cichosz et al. [4] found that in case of aluminium composite materials reinforced with Al_2O_3 fibres, the depth of heat affected zone was equal to about 30 μm, the matrix was slightly recast and made finer and ceramic fibres were generally left undamaged. The fibres directly affected by the spark discharges were degraded. The microhardness of the zone (148-157 HV) was higher than that of the bulk material. The surface roughness was found to be around $R_a = 3.5 – 4\ \mu m$. Khan [5] found that electrode wear (EW) increases with increase in current and voltage and wear of copper electrodes is less than that of brass electrodes.

The objective of presented paper is to investigate applicability and advantages of EDM to shaping aluminium composites reinforced with SiC particles.

The objective of this study is to investigate and report the effect of electrode diameter and pulse – on time on technological variables such as: tool wear rate, material removal rate and surface integrity of Al – 7% SiC_p as cast metal matrix composites (MMC). Two steel electrodes with different diameters ($Ø_{E1}$ = 0.96 mm, $Ø_{E2}$ = 2.51 mm) are used as tools.

2. EXPERIMENTAL PROCEDURE

2.1. Experimental equipments

The experiments were performed by using a die-sinking EDM machine of type SODICK AD3L. Table 2 lists the correlated parametric values adopted in this study. Figure 1 shows a photograph of this equipment and the experimental set up of the EDM process is schematically shown in Fig. 2.

Fig.1. Die – sinking EDM machine used

The EDM machine was equipped with a mechanical griper in order to fix the part. Four steel electrodes were prepared and used to complete the experiments.

The EDM machining of particle reinforced metal matrix composite material has a different machining mechanism from the conventional EDM due to the presence of two phases with completely different characteristics (Fig. 3).

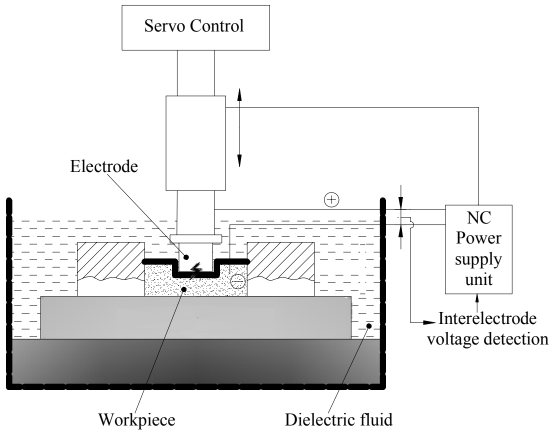


Fig.2. The schematic of the EDM set-up used in the present study

A ductile matrix has a low melting point and a high thermal conductivity, while the reinforcement quite reversely. High thermal resistance of composites has an adverse effect on efficiency of EDM process.

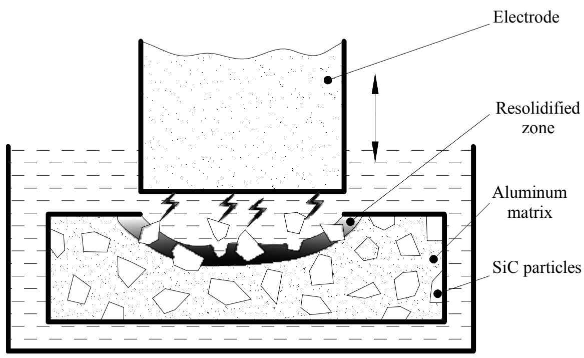


Fig.3. Schematic representation of EDM machining for PRMMC

2.2. Material used for the experiments

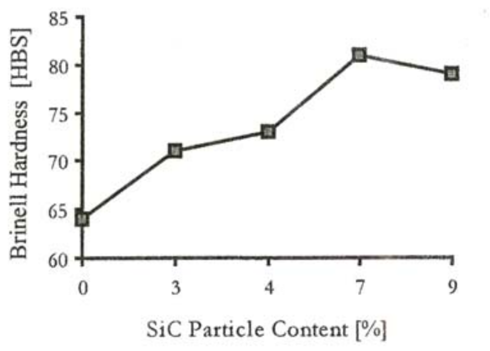
The material used in this study was a particulate reinforced composite, based on a commercial aluminium alloy of type ATSi7Cu3Mg. The composite was made by Vortex casting, in laboratory conditions, at the Material Science and Engineering Faculty, in Technical University of Iasi [6].

Table 1. Workpiece material specifications

Workpiece material	ATSi7Cu3Mg - MMC
Cu (%)	2.93
Si (%)	6.6
Fe (%)	0.51
Mg (%)	0.36
Ti (%)	0.15
Graphite (%)	3.5
SiC (%)	7

The nominal composition of the aluminium composite used in this study is presented in table 1.

Such composites, with graphite particle reinforcement (63 μm in average size) are recommended for tribological applications, because of graphite self – lubricating properties. To improve mechanical characteristics, silicon carbide particles (40 μm in average size) were introduced into the base alloy structure, simultaneously with the graphite particles. The evolution of hybrid composite mechanical properties, as a function of particle volume content, was estimated by Brinell hardness (Fig. 4).



(a)

Fig.4. Variation of composite hardness (a), tensile strength (b) and elastic modulus (c) as a function of ceramic particle contents [6]

2.3. Machining parameters and output factors

The machining parameters were identified and established as they are presented in table 2. The response variables were electrode wear (EW) and material removal rate (MRR).

Al – MMC hybrid composite with 7% SiC (refer to Table 1 for work material specifications) was drilled using steel tool with two different diameters and with different pulse on-times for each electrode. Positive polarity was maintained and water – soluble dielectric fluid VITOL KS was used.

The response variables are *MRR* and *EW*. *MRR* can be expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time:

$$MRR = \frac{w_b - w_a}{t} \tag{1}$$

where w_b and w_a are the weights of the workpiece before and after machining. In this study, penetration speed was estimated:

$$PS = \frac{l_h}{t} \tag{2}$$

where l_h is the penetration depth after machining and t is the machining time.

EW is expressed as the ratio of the difference of weight of the tool before and after machining to the machining time:

$$EW = \frac{w_{tb} - w_{ta}}{t} \tag{3}$$

where w_{tb} and w_{ta} are the weights of the electrode before and after machining.

The experimental layout is presented in table 2.

3. RESULTS AND DISCUSSION

Al-7% SiC hybrid composite was machined with precise diameter steel electrodes having two different diameters. The electrode length before and after machining was measured by using an electronically calliper (0.01 mm precision). The weight of the electrodes and workpiece was measured by using of an analytical balance 0.1 mg precision. Performing the experiments and applying regression analysis, the modelling of the desired response to several independent input variables can be obtained. In this study, for two independent variables under consideration (t_{on}, $Ø_E$), a polynomial regression model is obtained:

$$\Delta l_E = 0.11 \cdot \phi_E^{-0.31} \cdot t_{on}^{0.48} \tag{3}$$

The coefficient of multiple determination was: R^2 = 0.9998

$$\Delta W_p = 0.011 \cdot \phi_E^{0.95} \cdot t_{on}^{0.63} \tag{4}$$

In the case of the relation 4 the coefficient of multiple determination: R^2 = 0.9133

Table 2. Experimental matrix

Exp. No.	$Ø_E$ [mm]	ON-time (t_{on}) [μs]	OFF-time [μs]	Working time [min]	Peack current [A]	Δl_E [mm]	l_h [mm]	ΔW_E [mg]	ΔW_p [mg]
1.	0.96	50	50	30	6	0.79	0.97	4	2
2.	0.96	100	50	30	6	1.11	1.13	6.9	8
3.	2.51	50	50	30	6	0.59	1.84	21.2	11.3
4.	2.51	100	50	30	6	0.82	1.10	29.9	15.3

The status of the electrode tool wear affects the dimensional accuracy of machined components because the die sinking EDM process is a projection machining method.

As it can be observed from relation 3, when the electrode tool diameter increases, the electrodes wear decreases. This can be explained by the fact that a bigger electrode can dissipate easier the thermal energy from the working area. Longer pulse duration results in a large removal per discharge, which lead to increase the electrode wear and at the same time a higher surface roughness (Fig. 5).

MRR was found to increase with increase of electrode diameter and pulse-on time and the process is faster at the beginning of work and slows down because SiC particles sink into the spark gap (Fig. 6).

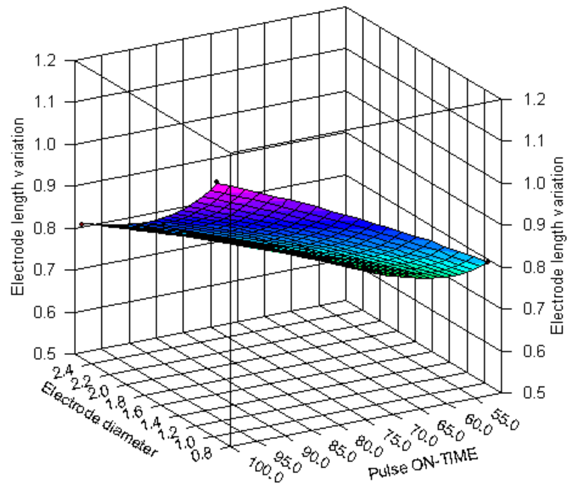


Fig.5. Variation of EW with electrode tool diameter and pulse-on time

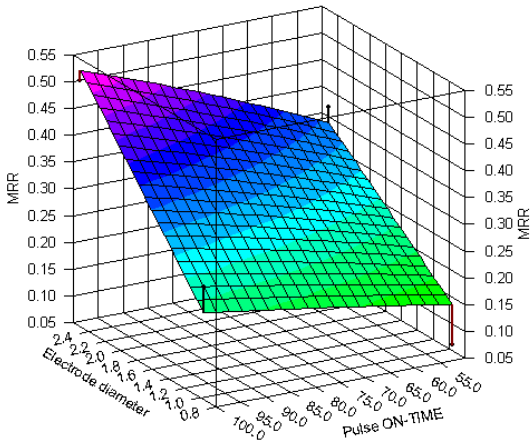


Fig.6. Variation of MRR with electrode tool diameter and pulse-on time

4. CONCLUSIONS

- The machinability by EDM process depends on the electrical conductivity of the workpiece. The results obtained indicate that Al-7% SiC hybrid composite can be machined effectively using EDM technology;
- EW was found to be smaller when bigger diameter for tool is used and increase when pulse on time is larger;
- MRR increases significantly when tool electrode diameter increases. It can be observed that the increase of pulse-on time lead to increase the MRR, but not as to increase tool electrode diameter;
- At higher pulse-on time the dimensional accuracy is affected.

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