Effect of Dielectric Fluid and Vibration on Performance in Electrical Discharge Machining of AlSiC Metal Matrix Composites

Mwangi J. W, Ikua B. W, Nyakoe G. N, Zeidler H and Kabini S. K

Abstract—Metal Matrix Composites (MMC) belong to a new generation of engineering materials that have desirable qualities such as high strength-to-weight ratio, high toughness, low value of coefficient of thermal expansion, high wear resistance, and thermal stability. They are therefore increasingly finding applications in the areas of aerospace, automotive, defense, biological and nuclear energy fields. Due to the nature of their application, these materials require to be machined to a high accuracy and to have a good surface finish. This requirement poses a challenge due to hard and abrasive nature of the materials. Mostly, grinding is the process used but the process is expensive and slow. Electrical Discharge Machining (EDM) can be used to address these challenges since it can be used to machine electrically conducting materials irrespective of their hardness.

This paper investigates the effect of using oil and deionised water as the dielectric fluids as well as the effect of introducing low frequency vibration in EDM machining of Aluminium Silicon Carbide (AlSiC) MMC. Experiments were carried out on AlSiC (AMC225XE) material using Sarix-100 high precision micro-erosion machine. A series of experiments were carried out with and without workpiece vibrations. For the experiments with vibrations a vibration frequency of 900Hz was used. The results of this study indicate that introduction of vibration raises the material removal rate but results to an inferior surface quality. Using deionised water as the dielectric results in lower machining time as opposed to Oil. However, this also results in an inferior surface quality and geometry of bore.

Keywords—Electrical Discharge Machining, AlSiC Metal Matrix Composite, Low frequency vibration, Material Removal Rate, Tool Wear Rate, Surface Quality

I. INTRODUCTION

COMPOSITES are materials that are composed of two or more distinct phases (matrix phase and reinforcing phase) and have bulk properties which are significantly different from those of any of the constituents. The reinforcing elements can be in the form of continuous fibers, discontinuous fibers, particulates or whiskers [1]. A composite with at least one metallic constituent material is referred to as a metal matrix composite, (MMC).

MMCs are used in making bearings, automobile pistons, cylinder liners, piston rings, connecting rods, sliding electrical contacts, turbo charger impellers and space structures among other applications [2].

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A. Electrical discharge machining

Electrical discharge machining is one of the earliest non-conventional machining processes and uses thermoelectric energy between the workpiece and an electrode for controlled material removal. It can be used to machine electrically conductive parts irrespective of their hardness, shape and toughness [3]. In recent studies, it has been possible to machine non-conducting ceramics using the assisting electrode method. This method allows the EDM process to proceed notwithstanding the electrically non-conducting properties of the ceramics [4]. There are two types of EDM machining namely, Die Sinking EDM and Wire EDM.

The basic set up of an Electrical Discharge Machining unit is as shown in Figure 1.

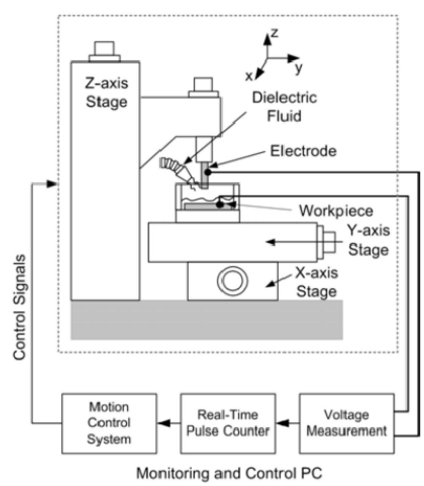


Fig. 1. Set up of an Electrical Discharge Machine [5]

EDM operates on the principle that when an electric current is applied between a workpiece and an electrode, submerged in a dielectric fluid, a potential difference is created. The electrode and the workpiece are separated by a small gap which is referred to as the spark gap. This potential difference results in pulsed electric discharges which then cause material to be removed from the workpiece.

B. Vibration of the workpiece

Researchers have used vibrations of different frequencies to test the performance of the EDM process. It has been reported that low-frequency and low-amplitude vibration can increase the material removal rate, and decrease the surface roughness and tool wear rate [6] whereby the vibration frequency and amplitude of the vibrating workpiece are the key factors in determining the optimum vibration [7]. According to Prihandana *et al*, [8] the application of vibration on the workpiece can speed up the machining time up to 3 times that of the machining process without workpiece vibration.

Ultrasonic vibration can be applied to the workpiece either directly or indirectly and has been reported to raise the process speed to up to 40%. It enables the machining of bores of less than 90μm in diameter with aspect ratios $>$40 for metallic materials. Using the assisting electrode principle as shown in Figure 2, it is also possible to machine bores of an aspect ratio $>$5 for nonconductive ceramic materials [9], [10] Ultrasonic vibration of the workpiece significantly reduces the inactive pulses and improves the process stability hence resulting to a higher material removal rate (MRR) [11]–[13]

The increased MRR in vibration is as a result of improved dielectric flushing from working zone as well as reduced arcing which allows more debris particles to be carried away from the machining area [14].

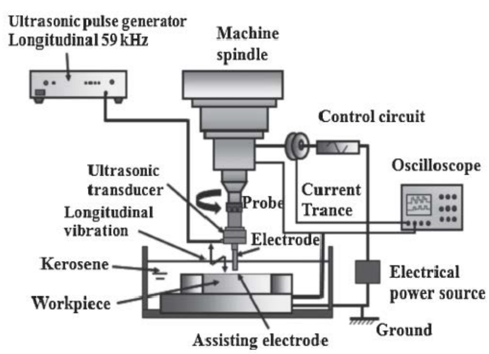


Fig. 2. EDM set up with Ultrasonic vibration and assisting electrode [4]

C. Choice of dielectric fluid

The dielectric fluid separates the electrode and the workpiece during machining and helps to make a conductive channel during ionization when suitable breakdown voltage is applied [15]. It also helps to flush the machined debris away. Oil and deionised water are the main dielectric fluids used in electrical discharge machining [15] but it is also possible to use dry EDM which uses gas instead of liquid as the dielectric medium [13].

Muniu *et al* [16] noted that the performance of dielectric fluids can be enhanced by addition of powders and established optimum machining conditions at 6 g/l which increased MRR by 32%, 44% and 7% while reducing EWR by 14%, 23% and 12% for diatomite, aluminium and copper powders respectively. According to Prihandana *et al* [8] introduction of graphite powder suspended dielectric fluid at concentration of 10 g/L reduces the machining time up to 5 times faster than machining time in pure dielectric fluid. Particle size, concentration, density, and thermal and electrical conductivity of the added powder materials are the most influencing factors in powder-mixed EDM [17].

II. Experimental Procedure

The experiments were conducted using SARIX 100 High Precision Micro Erosion Machine. Oil and deionised water were used as the dielectric fluids for investigation and there were two sets of experiments for each fluid. One set was vibration free and the other one included low frequency vibration. The effect of amplitude of the vibration was also established by varying the amplitudes in three levels (2.4μm, 6.40μm and 11.4μm peak-peak). There were five runs in each case. The machining coniditions are as shown in Table I.

TABLE I
Machining conditions

Description	Conditions
Dielectric fluid	Hedma 111 oil, deionised water
Open gap voltage	140V
Discharge current	11A
Pulse duration	700ns
Discharge energy	45μJ
Discharge frequency	100KHz
Target gap voltage	75V
Gain (regulation sensitivity)	650
Vibration frequency	900Hz
Vib. amplitudes (peak-peak)	2.40μm, 6.40μm, 11.6μm
Workpiece material	AMC225XE
Electrode polarity	Negative
Electrode material	Copper
Electrode diameter	3mm
Electrode rotation speed	834 rpm
Depth of bore	0.5mm

The experimental set up was as shown in Figure 3. The workpiece material used was AMC225XE which is a high quality aerospace aluminium alloy (AA2124). This alloy is reinforced with 25% volume ultrafine Silcon Carbide particles with an average size of 2-3μm.

The exact volume of every bore was measured using the volume measurement function of MountainsMap Scanning Topography surface analysis software. MRR and TWR were calculated using Equation 1 and 2 respectively. Bore surface topographies and roughness were measured using 3D laser scanning microscope Keyence VK-9700 and analysed using MountainsMap Scanning Topography software.

$$MRR = \frac{V}{t_{\mathrm{m}}} \tag{1}$$

$$TWR = \frac{\pi \times r^2 \times (h_{\mathrm{s}} - h_{\mathrm{f}})}{t_{\mathrm{m}}} \tag{2}$$

Where: V = Volume of the bore, r = radius of the electrode, h_s = electrode height before machining, h_f = electrode height after machining and t_m = machining time in minutes

III. Analysis

A. Effect of choice of dielectric

Deionised water dielectric produces more MRR and TWR compared to Oil dielectric as can be seen from Figure 4. However, oil produces the better surface quality as depicted by Figure 6 as well as superior bore geometry as revealed by

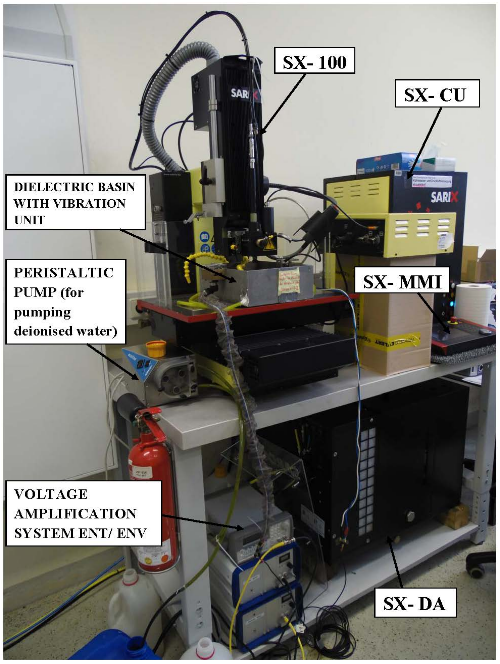


Fig. 3. Experimental machining setup

Scanning Electron Microscope(SEM) images in Figure 5. The SEM images show the presence of a small bump in the middle of the deionised water machined bore, which could be as a result of poor flushing at the centre of the bore. This is also demonstrated by the bore profiles in Figure 7 and Figure 8.

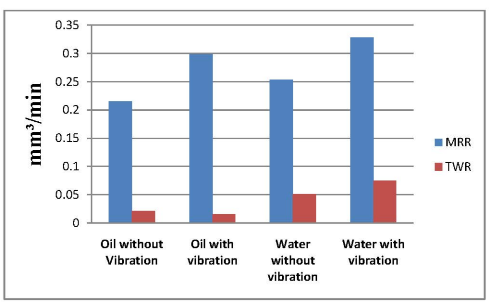
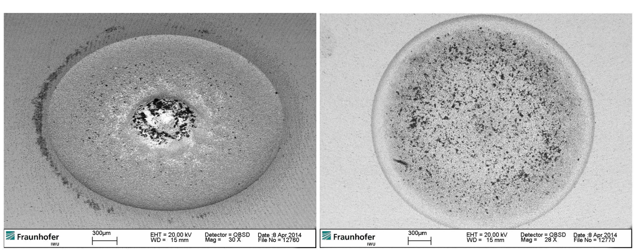


Fig. 4. Comparison of the dielectric fluids



(a) Water dielectric (b) Oil dielectric

Fig. 5. SEM images of machined surfaces

B. *Effect of low frequency vibration*

The results from the experiments show that by introducing low frequency vibration and using oil as the dielectric, the average machining time was reduced by 29.10% from 982.6 seconds to 696.6 seconds. The MRR was increased by 39.39% from 0.215mm^3/min to 0.298mm^3/min and the TWR reduced by 32.92% from 0.021mm^3/min to 0.015mm^3/min. Without vibration, the surface roughness values obtained by optical microscopy are R_a=0.641μm and R_z=7.34μm and after introducing vibration, the values rose to R_a=0.862μm and R_z=9.43μm.

While using deionised water as the dielectric fluid, introduction of vibration reduced the machining time by 30.91% from 812.8 seconds to 561.6 seconds. The MRR was increased by 29.56% from 0.253mm^3/min to 0.328mm^3/min and the TWR increased by 47.2% from 0.051mm^3/min to 0.075mm^3/min. Without vibration, the surface roughness values are R_a =0.709μm and R_z=7.65μm and after introducing vibration, the values rose to R_a=1.05μm and R_z=9.65μm.

Using oil as the dielectric fluid, the average bore depth in the vibration free experiments was 0.455mm whereas after introducing vibration, the average bore depth was 0.475mm. Bores machined with water dielctric had an inferior bore depth of 0.395mm without vibration and 0.420mm after vibration.

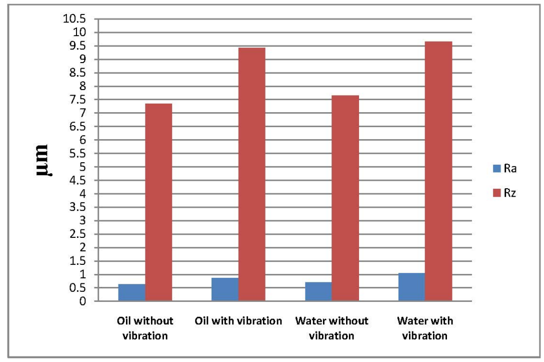
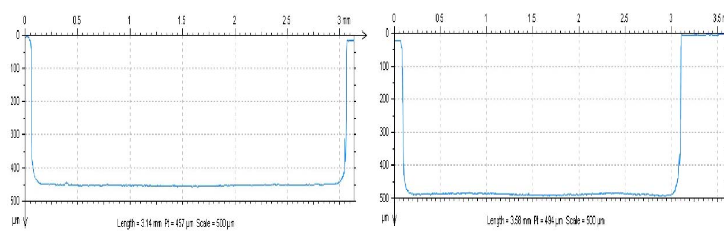
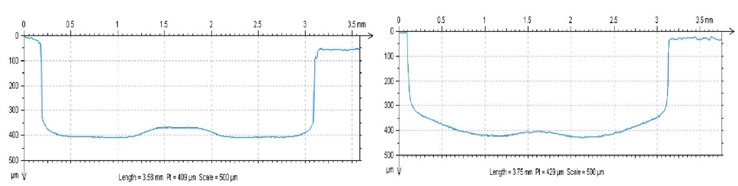


Fig. 6. Comparison of surface roughness values



(a) Without Vibration (b) With vibration

Fig. 7. Bore profiles obtained by machining with oil dielectric



(a) Without Vibration (b) With vibration

Fig. 8. Bore profiles obtained by machining with water dielectric

C. Effect of amplitude of low frequency vibration

Increase in amplitude of low frequency vibration results in decrease in machining time up to a maximum value after which a further increase results in increase in machining time. This is depicted in Figure 9. Increase in amplitude results in an increase in MRR and TWR up to a maximum after which a further increase results in a decrease as is depicted in Figure 10.

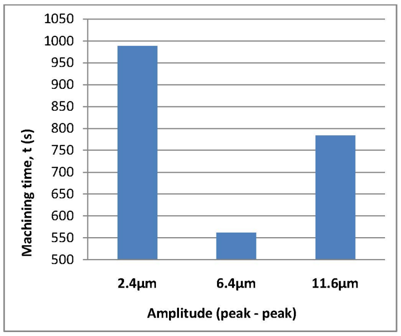


Fig. 9. Effect of amplitude on machining time

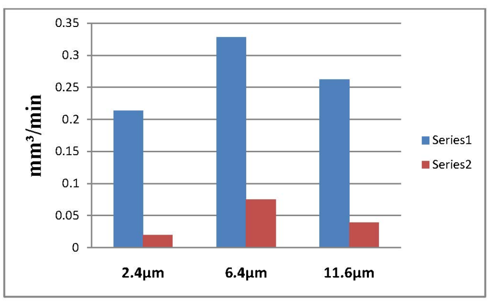


Fig. 10. Effect of amplitude on MRR and TWR in oil dielectric machining

IV. Conclusion

In this paper, the effect of dielectric fluids (Oil and Deionised water) as well as low frequency vibration in EDM machining of AlSiC is investigated. From the analysis, the following conclusions can be drawn.

- Deionised water would be the suitable choice of dielectric where greater MRR is the most desired performance measurement value but Oil would be the better choice if better surface quality and bore geometry are desired.
- By introducing vibration, it was possible to reduce machining time by 29.1 % and 30.91% in Oil and Deionised water dielectric fluids respectively. This is due to the fact that low frequency vibration improves the flushing process and therefore more debris can be flushed away.
- While the TWR reduced by 32.92% in Oil dielectric, it increased by 47.2% in deionised water dielectric.
- Introduction of vibration results in an inferior surface quality.

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