Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 12 (23): 2442-2447, 2012
ISSN 1812-5654 / DOI: 10.3923/jas.2012.2442.2447

Surface Quality of Electro-discharge Machined Aluminum Metal Matrix Composite

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Abstract: Aluminium alloys are conventional materials widely used in aviation, marine, automobile and electrical equipment. Aluminium alloy materials are relatively low cost, light weight and can be easily machined by both traditional and non-traditional machining processes. Aluminium Metal Matrix Composites (AMMCs), have been making inroads into various engineering applications where there are demands for strength and stiffness higher than those offered by the conventional aluminium alloys. Traditional machining of AMMCs, however, is challenging as their hard reinforcement tends to wrap around the conventional tool bit that leads to tool breakage. To address this problem, Electro-Discharge Machining (EDM) is being considered as a viable alternative to conventional machining. Key input process parameters of EDM such as the peak current, the pulse duration (ON-time) and pause duration (OFF-time) are varied to study their influences on the surface finish. The quality of the surface finish is indicated by the surface Roughness (Ra) and surface morphology of the metal surface. The effects of these parameters on the surface finish quality of alumina (Al_2O_3) particle-reinforced AMMC are then compared with those of an aluminium alloy. Performance of EDM machining on AMMC shows satisfactory result in surface roughness at low peak current, short ON-time and longer OFF-time. Response surface methodology is used to analyze and generate the mathematical model of output response.

Key words: EDM, surface roughness, surface morphology, Peak current, ON-time

INTRODUCTION

Composite are materials composed of two or more phases to shape a new material with improvement of properties. Aluminium Metal Matrix Composite (AMMC) is combination of aluminium base with a reinforcing constituent which is usually non-metallic and is commonly a ceramic (Chawla and Chawla, 2006). AMMCs are used in industries such as aviation, marine, automobile and electrical equipment. Their usage has been somewhat limited mainly due to the difficulty of machining AMMCs by conventional machining. Machining of AMMCs often is difficult because of the brittleness and abrasive nature of their reinforcement elements (Teti, 2002). This affects the cutting tool with rapid tool wear when composite materials are machined using traditional process (Teti, 2002).

The application of Electro-Discharge Machining (EDM) for material removal might be a feasible option which has yet to be tested on AMMC material. EDM is non contact process and uses an electrical current to remove material and this gives advantages over traditional machining process (Jameson, 2001).

Hard materials can be cut as long as they are conductor of electrical (Abbas *et al*., 2007). In EDM process, the workpiece and the electrode are maintained at a constant gap and are immersed in an insulating dielectric medium. When the potential difference voltage is applied between the tool and the workpiece, the dielectric material is ionized due to the electric field generated spark, produced between the workpiece and the tool which develops into an arc (Kumar *et al*., 2009).

A number of research works in the domain of EDM have been focused on the influences of EDM parameters on workpiece materials such as aluminium metal matrix (Cichosz and Karolczak, 2008; Nanimina *et al*., 2009), titanium alloy (Hascalik and Caydays, 2007) and tungsten carbide (Tomadi *et al*., 2009). Surface finish on composite materials such as SiC/Al AMMC when subjected to EDM process have been investigated and its impact on the fatigue strength of the material and other works address the optimal EDM performance (Kolahan and Bironro, 2008; Nanimina *et al*., 2011).

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Nanimina *et al.* (2011) studied the effect of EDM on Aluminium Metal Matrix Composite (AMMC). Results indicate that 30% Al_2O_3 reinforced aluminium metal matrix composite can be machined using EDM to obtain acceptable result in terms of MRR and TWR.

Currently, there is no specific research on optimization of process parameter setting of EDM in machining AMMCs.

This research is carried out to investigate the effect of EDM machining on the surface finish of AMMC and the results are assessed in comparison with that of aluminium alloy (Al 6061) using pure copper electrode. Aluminium alloy Al 6061 is employed in this research as a reference material.

Response Surface Methodology (RSM) technique is used to analyze and model the experiments. Design of Experiment (DOE) is a test referring to a plan, design, analysis and interpreting of experiment. DOE performs some changes to input variables called factors (parameters) of process and the corresponding changes to output called responses (Diamond, 2001). In analyzing an experiment, the models are fitted relating a response or quality characteristic to a set of controllable variables (Montgomery, 2005).

MATERIALS AND METHODS

In this study, die-sinking EDM Mitsubishi EA8 was used to machine a solid cylinder samples on AMMC and aluminium Al6061 workpiece material.

Scanning Electron Microscopy (SEM) was used to analyze the machined surfaces of AMMC and Al 6061 samples. The influence of a particular EDM parameter was analyzed by varying it while keeping other parameters constant. Response surface methodology is used in this research and Central Composite Design (CCD) is chosen to explores the relationships between parameters and output responses and to obtain an optimal response.

The chemical composition of the workpieces is presented given in Table 1 and 2. Their properties are presented in Table 3.

Table 1: Composition of AMMC (in % weight)

Al	O	Cu	Ni	Fe	Ti	Cr	Mn	Zn	Mo	Co
89.05	6.77	2.3	1.2	0.31	0.2	0.09	0.04	0.03	0.009	0.008

Table 2: Composition of aluminium alloy (in % weight)

Al	Mg	Fe	Si	Cu	Zn	Cr	Ti	Mn
96.5	1.0	0.7	0.6	0.3	0.25	0.2	0.15	0.15

RESULTS AND DISCUSSION

Effects of peak current on Ra: The influence of the peak current supplied to the electrode on Ra is observed (Fig. 1) by keeping the ON-time and OFF-time constant at 16 and 8 μsec, respectively. Higher peak current caused a poorer surface finish of AMMC. The peak current determines the size of spark energy. By increasing the peak current, the spark energy increases which create more craters and cracks leading to increasing surface roughness. The low increase in surface roughness of Al 6061 compared to AMMC is due to the superior thermal and electrical conductivities of Al 6061 than that of AMMC and the abrasive nature of the reinforcement particle present in AMMC. Materials with high thermal conductivity dissipate heat rapidly through the workpiece resulting in low value of Ra. High electrical conductivity of Al 6061 promotes higher machining efficiency.

Figure 2 and 3 show SEM view of machined surfaces of AMMC and Al 6061, respectively as the result of changes in peak current. Craters and micro-cracks can be seen especially for samples machined at high peak current (Fig. 2, 3).

It can be observed that the surface becomes rougher with an increase in peak current and this present further evidence of increasing surface roughness when peak current increases as shown in Fig. 1.

Effects of ON-time on Ra: The effect of ON-time applied to the electrode on surface roughness is observed

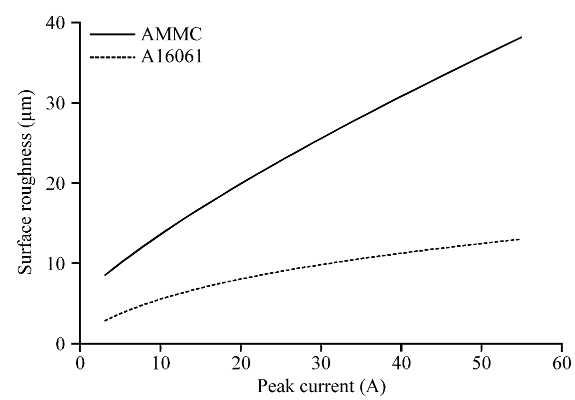

Fig. 1: Surface roughness vs. peak current

Table 3: Properties of AMMC and Al 6061

	Hardness (HRB)	Tensile strength (MPa)	Elastic modulus (GPa)	Electrical resistivity (Ωm)
AMMC	91	344.1	85.0	2.96×10^{-5}
Al 6061	60	328.0	68.9	3.99×10^{-7}

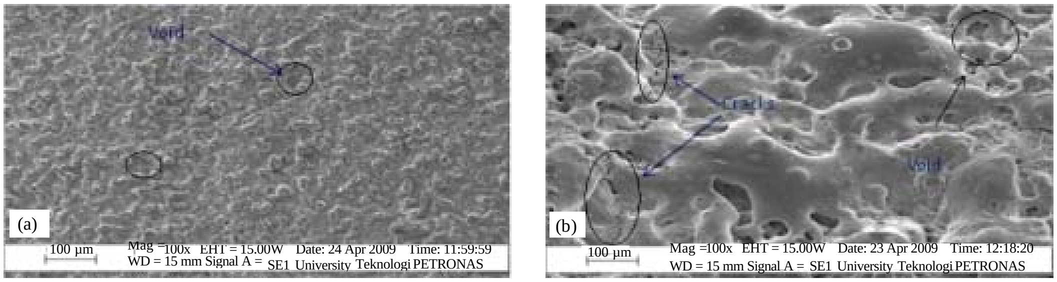

Fig. 2(a-b): SEM micrograph of machined surface of AMMC with ON-time: 16 µsec and OFF-time: 8 µsec at peak current (a) 10 A and (b) 35 A

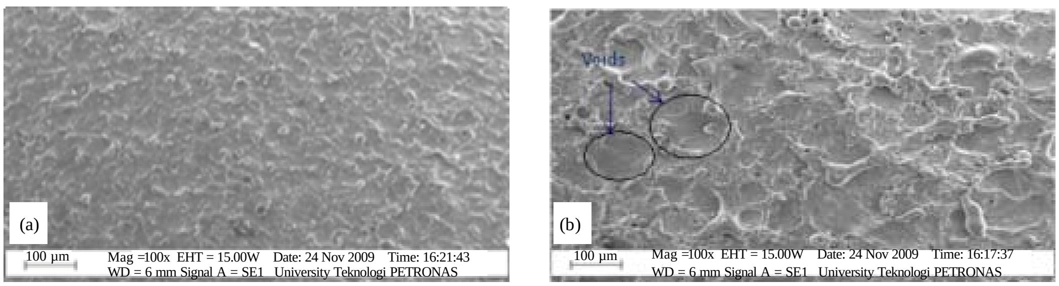

Fig. 3(a-b): SEM micrograph of machined surface of Al 6061 with ON-time: 16 µsec and OFF-time: 8 µsec at peak current (a) 3 A and (b) 25 A

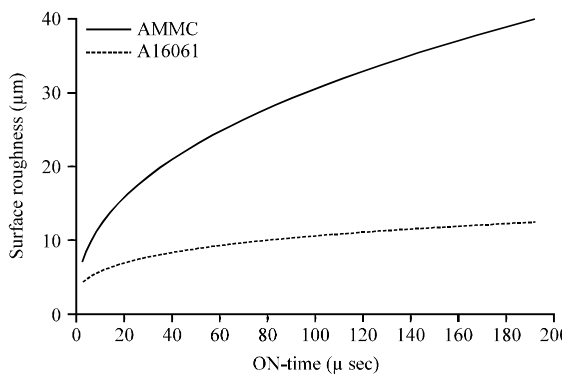

Fig. 4: Surface roughness vs. ON-time

(Fig. 4) by keeping constant the peak current and the OFF-time at 15 A and 8 µsec, respectively. Higher ON-time caused a poorer surface finish. Spark energy is also a function of ON-time. Increasing ON-time leads to increase the spark energy which increases crater and crack sizes. Due to the better machinability of Al 6061 compared to AMMC, the surface roughness of AMMC becomes comparatively worse than that of Al 6061.

Figure 5 and 6 show the SEM view of machined surfaces of AMMC and Al 6061, respectively by varying ON-time. It can be seen in Fig. 5a and 6a that the surface is less rough at short ON-time compared to Fig. 5b and 6b which are at longer ON-time.

It can be observed that when ON-time increases the spark erosion time increases, making more craters on the machined surface. Figure 5 and 6 justify the increase of surface roughness observed in Fig. 4.

Effects of OFF-time: The effect of OFF-time applied to the electrode on Ra is observed (Fig. 7) by keeping the peak current and ON-time at 15 A and 16 µsec, respectively. As the OFF-time is shorter, the number of discharge within a given period becomes more which leads to a faster machining but the surface roughness becomes worse.

The increase of OFF-time leads to decreasing of gap voltage. Fine machined finish can be observed by setting the machine parameters at a longer OFF-time. This can be due to the fact that as the OFF-time increases, discharges strike the surface of the sample less intensely and the resulting better erosion effect leading to a smoother surface finish.

Figure 8 and 9 present the SEM view of machined surfaces of AMMC and Al 6061, respectively with change in OFF-time, while keeping peak current and ON-time constant at 15 A and 16 µsec. Figure 8a and 9b show the

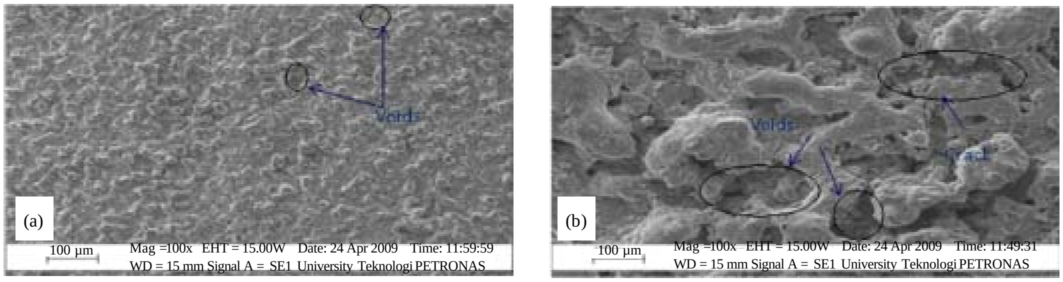

Fig. 5(a-b): SEM image of machined surface of AMMC at 15 A peak current, different On-time (a) 3 μsec and (b) 48 μsec and OFF-time of 8 μsec

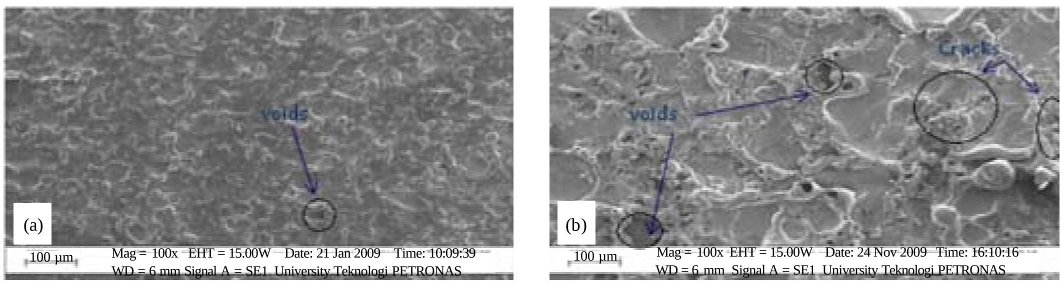

Fig. 6(a-b): SEM image of machined surface of Al 6061 at 15 A peak current, different On-time (a) 3 μsec and (b) 48 μsec and OFF-time of 8 μsec

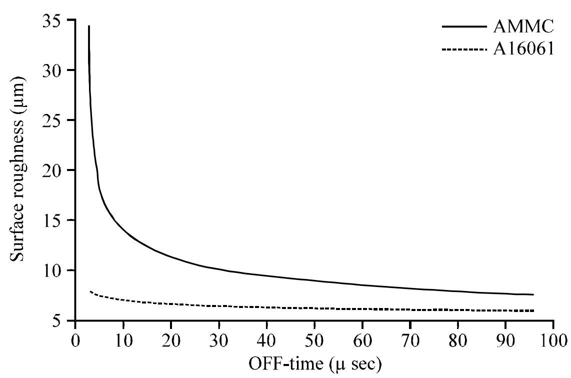

Fig. 7: Surface roughness vs. OFF-time

SEM micrograph at short OFF-time and it can be seen that the machined surfaces are rougher compared to Fig. 8b and 9b where the OFF-time is longer. When OFF-time is increased the machined surface becomes fine, this explains the decrease of surface roughness presented in Fig. 7.

Response surface methodology

Analysis on AMMC: The output responses were analyzed using Response Surface Methodology (RSM) in Design Expert software.

Figure 10 shows a three-dimensional graph for surface roughness. The increase in surface roughness with increasing peak current and ON-time can be seen clearly from this graph.

A mathematical model of the collected data was obtained by performing a linear regression analysis of the data using Design Expert software. The final equation with regression squared (R^2) equals 0.7868 for surface roughness is:

$$Ra = 6.196 + 0.626A + 0.124B - 0.171C \qquad (1)$$

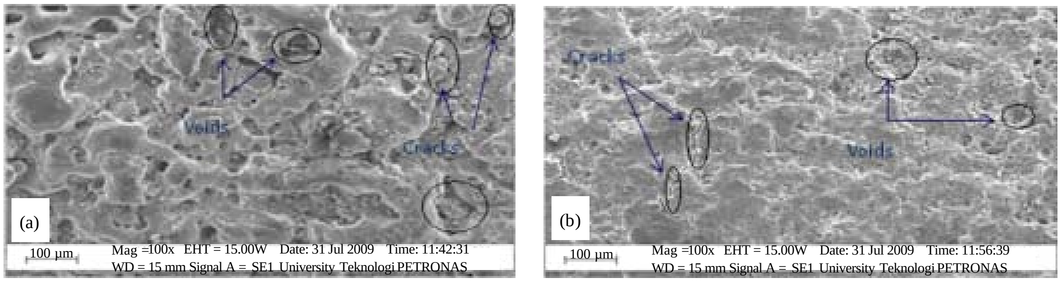

Fig. 8(a-b): SEM image of machined surface of AMMC at peak current of 15 A, ON-time: 16 µsec and with different OFF-time (a) 3 µsec and (b) 48 µsec

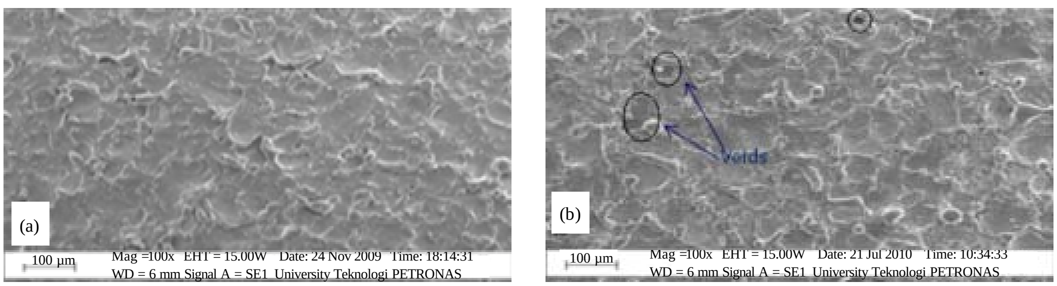

Fig. 9(a-b): SEM image of machined surface of Al 6061 at peak current of 15 A, ON-time: 16 µsec and with different OFF-time (a) 3 µsec and (b) 48 µsec

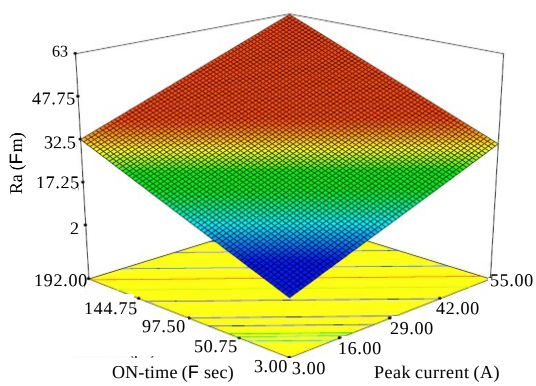

Fig. 10: 3-D graph for Ra of AMMC

where, Ra is surface roughness, A is peak current, B is ON-time and C is OFF-time.

Analysis on Al 6061: Figure 11 presents the 3-D graph for Ra of Al 6061. The effects of peak current and ON-time are observed, while. OFF-time is maintained constant at 25.5 µsec. As it can be seen, the Ra increases when peak current and ON-time increase.

Based on linear regression analysis of the experimental data, the mathematical model with R^2 equals 0.8676 for surface roughness of Al 6061 is:

$$Ra = 3.394+0.187A+0.032B-0.020C \quad (2)$$

where, Ra is the surface roughness, A is peak current, B is ON-time and C is OFF-time.

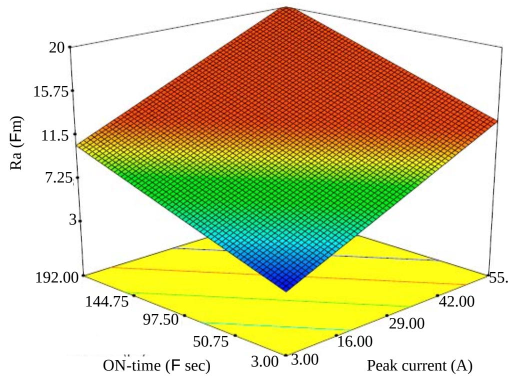

Fig. 11: Contour plot for Ra of Al 6061

CONCLUSION

Measurements of the surface roughness (Ra) of both samples show that 30% alumina-reinforced AMMC is more sensitive to the variation of the input process parameters of EDM compared to aluminium alloy. Effect on surface finish of Alumina-reinforced AMMC and aluminium alloy by EDM die-sinker process using electrolytic copper electrode has been investigated. It was found that the surface finish properties of AMMC are more sensitive to the variation of the EDM input process parameters as compared to aluminium alloy. Craters and micro-cracks observed are deeper and larger at higher peak current, longer ON-time and shorter OFF-time. Surface roughness of AMMC is coarser as compared to aluminium. Analysis using Central Composite Design (CCD) is found capable in generating mathematical models of output responses.

ACKNOWLEDGMENT

We would like to express our profound gratitude to the Universiti Teknologi PETRONAS for the financial support and the facilities for this study work.

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