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Analysis of Surface Topography of Al/Al_2O_3 MMC Machined during WEDM

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***Abstract*—** Wire electrical discharge machining (WEDM) is an effective technology of non conventional machining used to manufacture components with complex shapes and for machining of hard materials which are difficult to machine with conventional machining processes. Among hard and non ferrous materials Al/Al_2O_3 MMC is one which is used in this experimental investigation. The objective of this study was to analyze the parametric influence on the surface quality of machined surface and analysis of recast layer formation. For this purpose Scanning electron microscopy (SEM) and Energy dispersive X-ray spectroscopy (EDX) was used. The input parameters which were varied were Pulse on time (Ton), Pulse off time (Toff), Peak current (IP), Spark gap voltage (SV), Wire feed (WF) and Wire Tension (WT). In this study it was observed that high peak current (IP) and low pulse off time (Toff) increased the debris in the spark gap, which leads to abnormal arcing. Very less craters and no micro-cracks were formed at low pulse on time (0.6µs) and peak current (130A). Recast layer was seen at Ton = 1.2µs, Toff = 16µs, IP =190A, SV=30V, WT=1000 and WF=7. High amount of wire electrode wear was seen when parameters were set at T_{on} = 1.2µs, IP =190A

***Keywords*—** WEDM, Al/Al_2O_3 MMC, SEM, EDX

I INTRODUCTION

Instead of classical mechanical power Wire electrical discharge machining (WEDM) employs only physical principles for cutting of the materials. It is a erosion process to get complex 2d and 3d shapes. Complex shapes can be produced due to use of small wire and work gap. High degree of accuracy with fine surfaces is obtainable in WEDM. It requires selection of appropriate set of parameters for optimum results. Brass wire with diameter of 0.3–0.02 mm is usually used as a tool electrode. In WEDM material removal is in the form of microscopic particles which occurs by periodically recurring electrical discharges among work piece and wire. Discharged material particles are subsequently carried away from the cut area by a flushing jet of dielectric liquid. This liquid also provides cooling of the component which is being machined [1,2]. Metal matrix composites (MMCs) are among the materials which are tough to machine using traditional machining process. The ceramic particles which enhance the mechanical properties of MMCs and make them desirable significantly reduce cutting tool life due to rapid abrasive wear [3] From the last three decades the use of MMCs has increased due to their attractive properties, their potential to be available at low cost and relative ease in fabrication technology [4]. It could be an economic choice for machining these materials using WEDM.

Many researchers have worked on WEDM of MMCs. Rao [5] investigated the optimization of WEDM and revealed that the quality of a wire EDM surface is strongly influenced by its parameter settings and the material which to be machined. Rozenek et al. [6] worked on WEDM characteristics of metal matrix composites. In this study, SiC and Al2O3 particulate-reinforced aluminum matrix composites were machined by WEDM using one-factor-at-a-time methodology. They found current, voltage, and on-time as significant parameters on cutting rate and surface finish. There are several factors which effects on the resulting quality of the machined surface. Those include machine input parameters and a set of mechanical and physical properties of the material to be machined [7, 8]. Yue and Dai [9] found that surface finish of unreinforced matrix was superior to Al_2O_3 preinforced composites. In another study [10] the surface finish of MMCs was found to be inferior to that of the matrix alloy. Cheng [11] in his investigation used high speed wire electrical discharge machining for processing of the pure aluminium oxide film to check its performance influenced by the WEDM. This method proved to greatly improve the outputs of the research by reducing the abrasive wear and adhesive wear, and increasing the anti-erosion ability.

Literature survey reveals that is necessary to find the optimum machine input parameters for individual materials to ensure effective machining with accuracy and improved surface quality. Another objective of this study was to investigate surface and undersurface defects, cracks etc. which can occur due to inappropriate selected machining parameters. Those defects and cracks significantly affect the life and accuracy of the machined parts. Investigation on wire electrode wear was also done through SEM to check different parameters influencing them.

II EXPERIMENTATION

Al/Al_2O_3 MMC having dimensions 140mm x 70mm x 12mm has been used as work piece material for the present study. This composite contains powdered form 12% alumina particles having 200-300 mesh size are reinforced with aluminium metal. ELEKTRA SPRINTCUT WEDM machine was used to perform experiments which were designed with the help of Box Behken Design (BBD). While performing experiment each time, a particular set of parameter combination was chosen and work piece was cut. A 5 mm × 5 mm rectangular cut was taken on the work piece. ELAPT software was used to generate CNC code for cutting which was supplied by the manufacturer. A set of preliminary

Harsimran Singh, Sahil Singh, and Tejbinder Singh "Analysis of surface Ttpography of Al/Al_2O_3 MMC machined during WEDM," *International Journal of Scientific and Technical Advancements*, Volume 4, Issue 1, pp. 157-160, 2018.

experiments was performed for the purpose of selecting the process parameters and their levels. Table 1 shows the range of selected parameters for main experimentation.

Table 1 Limit of machine setup Parameters

Process Parameters	Symbol	Units	Range (machine units)	Range (actual units)
Pulse on Time	Ton	µs	110-122	0.6-1.2 µs
Pulse off time	Toff	µs	43-53	16-32 µs
Spark gap voltage	SV	V	20-40	20-40 volt
Peak Current	IP	A	130-190	130-190 ampere
Wire Feed	WF	m/min	7-9	7-9 m/min
Wire Tension	WT	gram	8-10	1000-1400 gram

After experimentation the machined samples were prepared and etched with Kellers reagent (2ml Hydrofluoric acid, 3 ml Hydrofluoric acid, 5 ml nitric acid and 190 ml distilled water) for microscopic testing. The surface texture analysis was done by using scanning electron microscope (JEOL, Japan, JSM-6610LV).

III SURFACE TEXTURE ANALYSIS

A. Analysis of machined surface topography

The surface topography of the machined surfaces reveals its quality which includes micro-cracks, pull out of the material, formation of debris, recast layer and phase transformations on the surface. The surface properties alter due to the effect of input process parameters like pulse on time, pulse off time and peak current etc. The pulse on time (1.2µs) and peak current (190A) were observed as the most significant parameters affecting the surface properties. The increase in pulse on time increases the amount to heat transfer to machined surface thus melting more material and results in the formation of deep craters on the machined surface as shown in figure 1(b). Some of the molten material produced by the discharge was carried away by the de-ionized water. The remaining molten material re-solidified to form lumps of debris as observed in Figure 1(a). During short pulse on-time, electric sparks produced small craters on work surface as shown in Figure 1(a). At higher pulse on time value some of the particles protruded and completely dislodged from the machined surface as observed in Figure 1(b). The main possible reason for deep and big craters is the oxidation reaction, the impulsive force of dielectric pressure concentrated on localized spark gap area.

It was observed from SEM micrographs Figure 2 (a-b) that very less craters and no micro-cracks were formed at low pulse on time (0.6µs) pulse off time (32µs) and peak current (130A). Due to low peak current and pulse on time, the work surface is impinged with less intensive discharge. Increase of debris in the spark gap due to high peak current and low pulse off time lead to abnormal arcing. The abnormal arcing decreases the discharge rate and material removal rate [12].

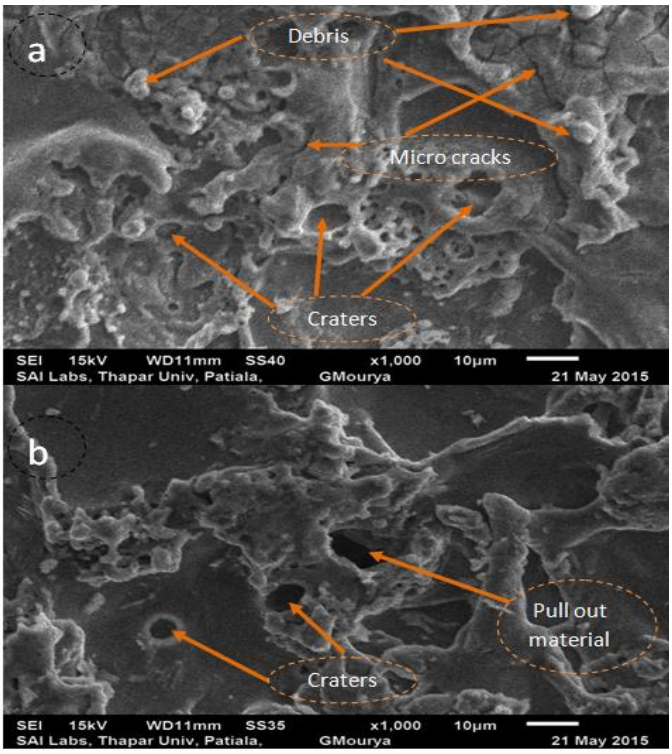

Fig.1. SEM micrographs showing large number of craters, pull outs and cracks that were formed at higher Ton = 1.2µs, IP = 190A, Toff = 16µs.

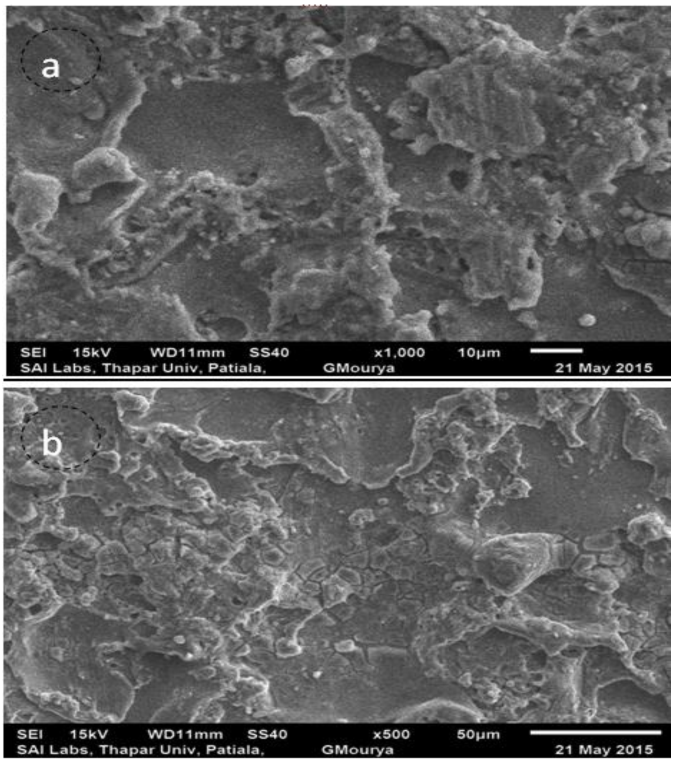

Fig.2 SEM micrographs showing less number of craters, pull outs and cracks that were formed at lower Ton = 0.6µs, IP =130A, Toff = 32µs.

Harsimran Singh, Sahil Singh, and Tejbinder Singh "Analysis of surface Ttpography of Al/Al_2O_3 MMC machined during WEDM," *International Journal of Scientific and Technical Advancements*, Volume 4, Issue 1, pp. 157-160, 2018.

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B. **Recast layer formation**

The recast layer is defined as the material melted by electrical discharge and re-solidified on the work surface without being ejected nor removed by dielectric fluid [13]. It is very difficult to remove and its appearance is observed through a scanning electron microscope at different levels of magnification. Mostly the recast layer is observed at the cross section of WEDM process. The recast layer was observed at high pulse on time, peak current and low pulse off time. As shown in figure 3 the recast layer has non-uniform and wave like pattern.

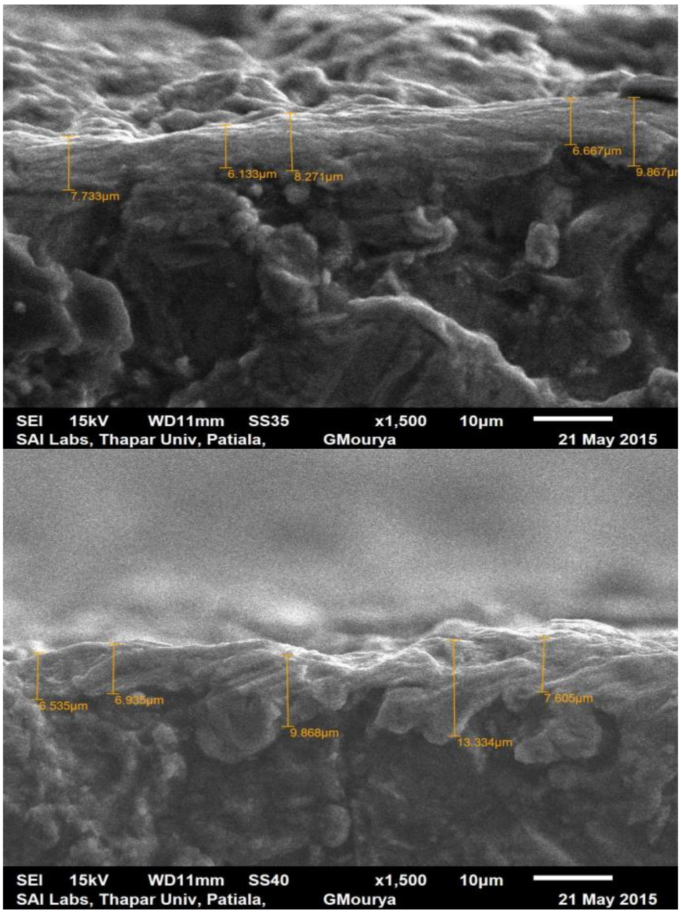

Fig.3 Microstructure of recast layer of WEDM sample which was seen at Ton = 1.2µs, Toff = 16µs, IP =190A, SV=30V, WT=1000 and WF=7

C. Analysis of wire electrode topography

Figure 4 (a-d) shows the micrographs of worn wire electrode. The different craters and residuals of debris adhered to the surface of wire electrode. The residuals of copper, carbon, oxygen and aluminium were detected in wire electrode through EDX as shown in Figure 4 (d). This may be due to the melting and re-solidification of aluminium and brass wire electrode after WEDM. Higher discharge energy in the spark gap is generated when pulse on time and peak current is increased. Hence it may result in increase of wear of wire electrode. Craters became deeper and wider when pulse on time was increased. The presence of debris in the gap which is not flushed properly by dielectric fluid may result in arcing. This arcing also results in the wire breakage.

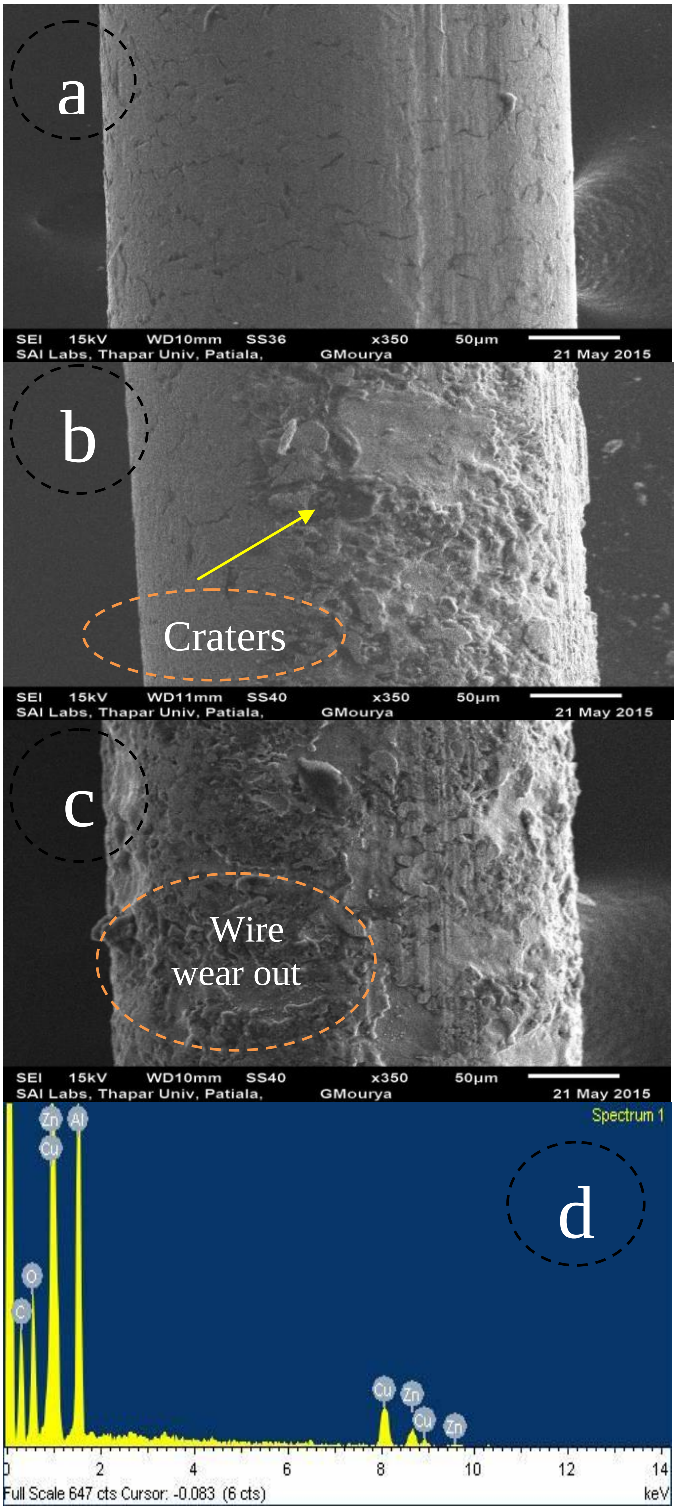

Fig.4 SEM micrographs of machined wire electrodes (a) T_{on} = 0.6µs, IP = 130A (b) T_{on} = 0.9µs, IP = 160A (c) T_{on} = 1.2µs, IP =190A (d) EDX of wire wear out

Harsimran Singh, Sahil Singh, and Tejbinder Singh "Analysis of surface Ttpography of Al/Al$_2$O$_3$ MMC machined during WEDM," *International Journal of Scientific and Technical Advancements*, Volume 4, Issue 1, pp. 157-160, 2018.

IV CONCLUSIONS AND DISCUSSION

In this study the effect of six input process parameters i.e. Pulse on time (Ton), Pulse off time (Toff), Peak current (IP), Spark gap voltage (SV), Wire feed (WF) and Wire Tension (WT) on surface topography of Al/Al_2O_3 MMC was investigated. Box-Behnken technique was applied for experimental design work. After the completion of experimental work machined samples and used wire samples of different parameters were collected and prepared for metallographic examination through SEM and EDX.

Finally it can be concluded that:

1. Higher setting values of pulse on time and peak current causes deep and wide craters on the machined surface which deteriorates the surface characteristics of machined surface.
2. The recast layer increases with the increase of pulse on time and peak current.
3. High peak current and more spark frequency resulted in wire rupturing.
4. Pulse off time less effects wire wear.
5. Debris, micro cracks and pull outs were observed at high pulse on time.
6. EDX analysis showed the residuals of carbon, copper and zinc in machined samples. It can be due to transferring of melted brass electrode to the workpiece.
7. Less surface defects like craters, micro-cracks and pull outs were formed at- Ton (0.6μs), Toff (32μs), WF (7m/min), WT (1000), SV (30) and IP (130A).

NOMENCLATURE

WEDM – Wire electrical discharge machining
T_{on} – Pulse on time
T_{off} – Pulse off time
SV –Spark gap voltage
IP – Peak current
WT – Wire Tension
WF–Wire Feed
MMCs– Metal matrix Composites

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Harsimran Singh, Sahil Singh, and Tejbinder Singh “Analysis of surface Ttpography of Al/Al_2O_3 MMC machined during WEDM,” *International Journal of Scientific and Technical Advancements*, Volume 4, Issue 1, pp. 157-160, 2018.