Investigations into Wire Electro-Discharge Machining of A6061/Al_2O_3p Composites

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Abstract: Wire electrical discharge machining (WEDM) is a widely employed non-traditional machining process. Metal Matrix Composites (MMCs) are newly developed materials having favourable mechanical properties like high strength, hardness, wear resistance and strength to weight ratio. In this study, experimental investigation based on the Taguchi method involving four control factors with three levels using orthogonal array L18 is reported. Taguchi orthogonal array was used to study the effect of combination of reinforcement, pulse on-time, off-time and servo voltage on Material Removal Rate, kerf width and surface finish. A6061 and A6061/Al_2O_3/10_p have been machined in this study. The wire electrode breakages were found during the machining A6061/ Al_2O_3p composite. The locations and frequency of wire breakage was studied to identify the reasons of wire breaking during machining of these materials. It was found that the presence Al_2O_3p results in lower MRR and higher Surface roughness (Ra). The Material removal rate varied between 31.25 to 61.25 mm^2/min Al6061 alloy and 16.25 to 33.25mm^2/min for MMC. The Surface roughness varies between 2.11 and 3.3 µm for Al6061 alloy and 2.18 and 4.76 µm for MMC.

Keywords: ***MMC's, Wire breakage, WEDM, Kerf Width, Taguchi Method***

1 Introduction

Inspite of superior property like high strength to weight ratio, high hardness of reinforcements results into difficulty in machining of metal matrix composites (MMC's) (Yan et al., 2005, Clyne, 1993, Patil and Brahmankar 2010).

Wire electrical-discharge machining (WEDM) has been considered as one of the promising choices to machine these composite materials. WEDM has been proved to produce different shapes in machining of dies, punches, tools, and electronic parts (Patil and Brahmankar, 2010, Yan et al., 2005). However, wire breaking during the machining process is a serious problem it reduces the machining accuracy and quality of the machined surface in addition to reduced productivity (Yan et al., 2005; Patil and Brahmankar, 2010, Shandilya et al., 2012).

Over the years, the role of ceramic reinforcement on the machining performance such as surface quality, cutting rate and process has been identified (Guo et al., 2002; Srivastava et al., 2014; Sharma et al., 2014). According to Shandilya et al. (2012), during the WEDM of MMCs, wire breakage occurs when the wire comes in contact with non-conducting ceramic particles. However, the wire breakages are generally attributed to high frequency of discharges and concentration of discharges (Rajurkar and Wang, 1991; Kinoshita, 1982). The present study is an attempt to understand the role of ceramic reinforcements in wire breakages.

2 Experimental Work

The experiments were performed on ELEKTRA SPRINTCUT 734 of Electronica machine tool. The preliminary experiments were conducted by using one-factor-at-one-time.

B. Iyer, S. Nalbalwar and R. Pawade (Eds.)
ICCASP/ICMMD-2016. Advances in Intelligent Systems Research.
Vol. 137, Pp. 94-99.

The effects of parameters viz. ceramic reinforcement, pulse on-time, pulse off-time and servo voltage, on the performance measures such as metal removal rate (mm^2/min), Kerf width (mm) and surface roughness (Ra, µm) have been studied using L_{18}orthogonal array. The present work was carried out on Al6061 and A6061/Al_2O_{3p}. Negatively polarised high conductive diffused zinc brass core with 0.25mm was used as the tool. The machined work piece was 25mm high. The deionised water was used as dielectric and electrical conductivity was maintained at 20µS/m the dielectric temperature was kept at 20ºC. The MRR calculated by cutting speed (mm/min) into height of work material (mm). Profile Projector was used to measure the kerf width of work piece. The surface roughness was measured by using Mitutoyo SJ 210 surface roughness tester.

3 Results and Discussion

3.1 One-factor-at-a-one-time

Figure 1 shows the influence of pulse on-time on cutting speed. The cutting speed was greater in base alloy as compared to A6061/Al_2O_3p. This can be attributed to greater electrical and thermal conductivities of base alloy as compared to MMC. Figure 2 shows the effects of pulse on-time on surface topography in terms of average and maximum roughness values. The on-time was found to be insignificant effects on surface roughness in MMC. This can be due to the presence of alumina particles figure 2.

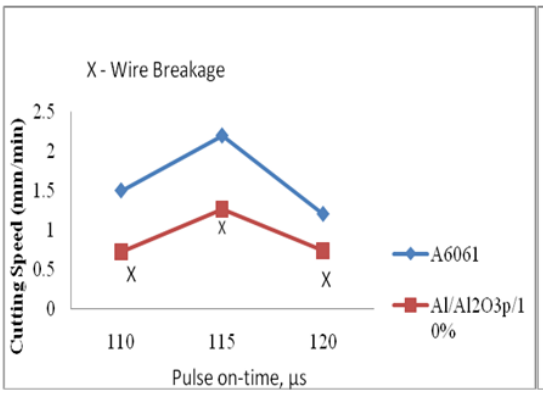


Fig. 1. Pulse on-time vs. cutting speed

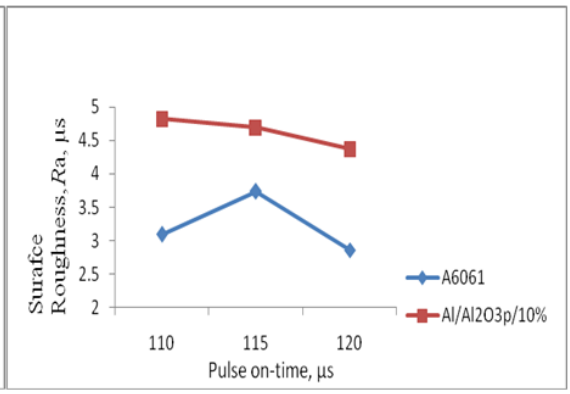


Fig. 2. Pulse on-time vs. surface roughness

In A6061/Al_2O_3p the surface roughness decreases with increase in pulse on-time. The results of preliminary set of experiments revealed that cutting speed of A6061/Al_2O_3p was lower than that of base alloy. A6061/Al_2O_3p was required more gap voltage compare to base alloy. Gap voltage was more at the second level of pulse on-time for A6061/Al_2O_3p.Figure 4 shows that cutting speed was greater in base alloy as compared to A6061/Al_2O_3p reinforced composite. The wire breakage was severe in A6061/Al_2O_3p as compared to the base alloy.

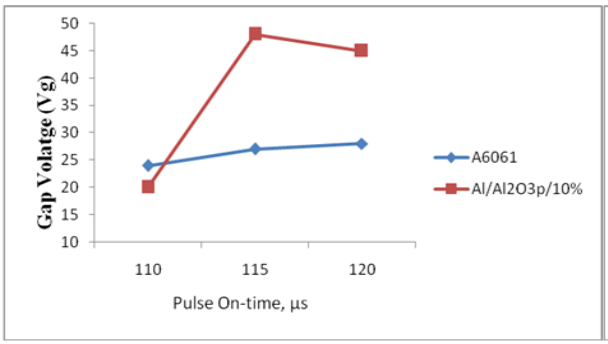


Fig. 3. Pulse on-time vs. gap voltage

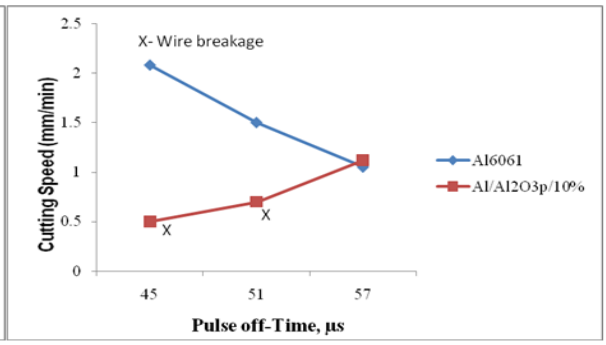


Fig. 4. Pulse off-time vs. cutting speed

3.2 Taguchi experiments

Taguchi' design methodology has been used for preparation of design matrix for this experiment. Before conducting the experiments, the four parameters were decided to be varied namely material, Pulse on-time (Ton), Pulse off-time (Toff) and Servo voltage (Sv). The process parameters and their level are given below table 1.

Table 1 Parameters and levels

Parameter		Levels		
	Symbol	1	2	3
Material, %		Al6061	A6061/Al_2O_3p	---
Pulse on-time, µs	T_{on}	110	115	120
Pulse off-time, µs	T_{off}	45	51	55
Servo voltage, V	S_v	20	30	40

3.3 Material Removal Rate (MRR)

The material removal rate is calculated by cutting speed into height of work piece. The analysis of S/N ratio shows that the optimum machining performance for the MRR is obtained at material of base alloy (level 1), 0.85 µs pulse on time (level 2), 20V servo voltage (level 1), 36 µs Pulse off time (level 1) settings. MRR was greater at low level of servo voltage and pulse off-time. Figure 5 shows the S/N ratios plots for MRR. In order to study the significance of the process variables towards MRR, analysis of variance (ANOVA) was performed. It was found that the material and pulse on-time are significant process parameters for MRR. There is no significant change in MRR by servo voltage and pulse off-time. By regression analysis, the correlation has been obtained, equation 1.

MRR = 204.715 - 0.545833 Ton - 0.391667 SV - 1.79167 Toff (1)
Correlation coefficient 'r- value' = 0.95

On-time was found to be the major factor on MRR (54.32%), volume fraction was found to be the second rank factor (27.78%). The percentage contribution of servo voltage was 6.84%.

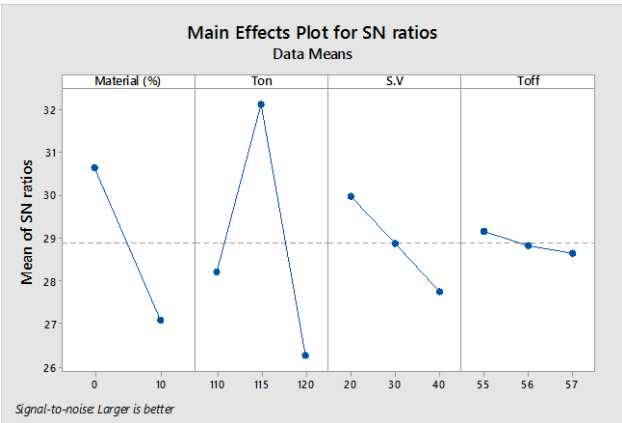


Fig. 5. Main effects plots for S/N ratios MRR

3.4 Kerf Width

The kerf width was measured at three places in the top and bottom the average is considered as the result. At higher pulse-on time the kerf width was found larger at the entrance of the work material. The reason may be improper flushing at the inner side of the slit. It was observed that kerf width decreases with increase in the pulse on-time and servo voltage. The analysis of S/N ratio shows that the optimum machining performance for

the kerf width is obtained at material of A6061/Al_2O_3p (level 2), 0.6 µs pulse on time (level 1), 20V servo voltage (level 1), 36 µs Pulse off time (level 1) settings.

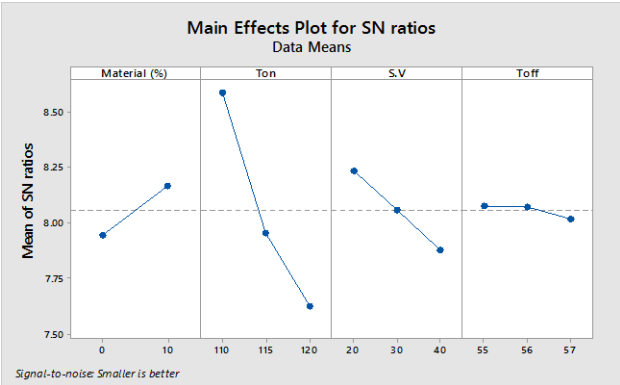


Fig. 6. S/N ratios of kerf width

On-time was major factor on kerf width with contribution of 74.54%. The percentage contribution of servo voltage was 10.24% and alumina particles were 5.76%. By regression analysis, a correlation has been developed, equation 2.

Kerf Width = -0.189306 + 0.00435 Ton + 0.000816667 SV + 0.00108333 Toff (2)
Correlation coefficient 'r- value' = 0.95

3.5 Surface roughness

The surface roughness values, R_a depend on the energy supplied to the workpiece. The energy input in this case is calculated by the pulse on-time and voltage. The pulse on-time and the servo voltage were found to be the most significant parameter for the surface roughness. The optimum machining performance for the surface roughness is obtained at material of base alloy (level 1), 0.6 µs pulse on time (level 1), 40V servo voltage (level 3) and 36 µs pulse off time (level 1) settings. The servo voltage was found most influential factor on the cutting speed 35.29%. The percentage contribution of pulse on-time was found 32.53%. By regression analysis, the correlation has been obtained, equation 3.

Surface roughness = -2.24286+ 0.0446167 Ton-0.0381833 Sv + 0.0216667 Toff (3)

Correlation coefficient 'r value' = 0.83

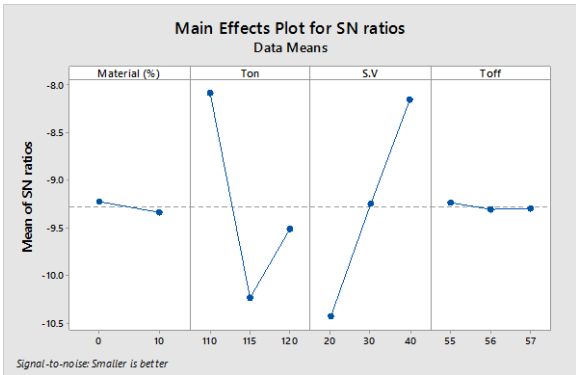
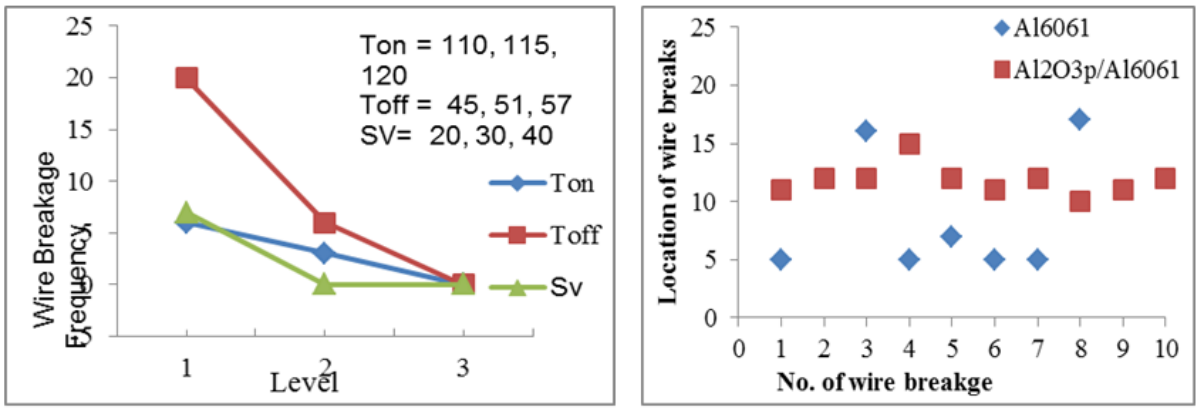


Fig. 7. Main effect plots for S/N ratios of surface roughness

3.6 Wire breakage frequency for A6061/Al_2O_3p

Wire breakage frequency was found higher in A6061/Al_2O_3p as compared to the base alloy. It can be attributed to the ceramic reinforcements.

Wire breakage frequency was found to increase with reducing pulse off-time. At longer pulse off-time wire breakages did not occur, but as the pulse off-time decreases, it reaches up to its maximum value due to higher pulse frequency. Wire breakage frequency was found to increase with reduced on-time. This is in disagreement with earlier findings on wire breakages during machining of monolithic materials. Figure 8 shows the wire breakage frequency. If the mean machining voltage is higher than the set voltage level, wire advances, and if it is lower, the wire retracts. Therefore, the higher the value for servo voltage, the gap between work piece and electrode wire becomes wider. When a smaller value is set for servo voltage, the mean gap voltage becomes narrower, which leads to an increase in number of electric sparks.



(a) (b)

Fig. 8. a) Wire breakage frequency b) Location of wire breakage on workpiece

The locations at which the wire was found to brake are shown in Figure 8 b). The wire breakages were found to occur at different locations for base alloy and the MMC. In case of base alloy wire was found to break below the centre of workpiece. However, during cutting of the MMC wire was found to break in the middle and above the centre of the machined surface. Wire breaking below the centre of workpiece height can be attributed to the increase in discharge energy due to high pulse frequency. During machining of A6061/Al_2O_3p composite wire breaks either at the middle of the workpiece height or even above the centre along the height of work piece. This can be attributed to the excessive wear of the wire due to ceramic reinforcements. Wire breakages can be avoided by selecting appropriate parametric combination. Higher Pulse on-time, off-time and servo voltage can be used to avoid risk of wire breakages, however this affects on the economics and dimensional accuracy of the process.

4 Conclusions

This work was carried out to study the wire electro-discharge machining of metal matrix composites. The effect of WEDM on wire breakage and other performance measure was studied. The major conclusions from the present work are summarized as below,

- Volume fractions of ceramic reinforcement, Pulse on-time were found to be significant on MRR, cutting speed and kerf width.
- Pulse on-time and servo voltage were found to be significant on Ra.
- Wire breakage frequency was found to increase with volume fraction of reinforcement.
- MRR was ranged between 16.25 and 33.25mm^2/min for A6061/Al_2O_3p MMC.
- The cutting speed was ranged between 0.65 and 1.33 mm/min for A6061/Al_2O_3p MMC.
- Kerf width was in the range of 0.368 to 0.411 mm in machining of A6061/Al_2O_3p MMC.
- The surface roughness range within 2.189 and 4.768 µs for A6061/Al_2O_3p MMC.
- The wire breakage frequency was found to decrease at longer pulse on-time.

Acknowledgement

Authors would like to thank Mr. Swapnil G. Pujari and Mr. Mahesh D. Kathar, Vision Tech., Waluj, A'bad for providing the machining facilities and helping during experimentation.

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