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Effect of Various Parameters on Response Characteristics of WEDM during Machining of Al/SiCp-MMCs

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Abstract - **In this experimental study, wire cut electrical discharge machining (WEDM) is adopted in machining of silicon carbide particulate reinforced aluminium metal matrix composites (Al/SiCp-MMCs). In the experiments total six machine input parameters are varied using one factor at a time strategy to explore their effect on response characteristics including cutting speed, surface roughness and spark gap. Moreover Wire breakage was found to pose limitations on the cutting speed of MMCs. The present study also investigates the causes of wire breakage in machining of Al/SiCp-MMCs and suggests their remedial actions. Reinforcement percentage of SiC particles and pulse on time are found to have significant effect on the response characteristics. Test results reveal that in machining of Al/SiCp-MMCs, higher cutting speed could be achieved with optimum setting of pulse off time and spark gap set voltage without wire breakage. Additionally high wire feed rate, a high flushing rate and setting of optimum wire tension is required to avoid wire breakage. An optimum range of machine input parameters has been reported as the outcome of this work for the successful machining of Al/SiCp-MMCs with minimum chances of wire breakage for further research in this area.**

Keywords: **WEDM, Al/SiCp-MMCs, Process parameters**

I. Introduction

Metal matrix composites (MMCs) are newly advanced materials having the properties of light weight, high elastic modulus, high specific strength, good wear resistance, improved stiffness and a low thermal expansion coefficient, etc. These materials have gained importance in various fields like aerospace, defense, automobile and sports [1]. However, the reinforcement material (i.eSiC, Al_2O_3 etc.) makes it difficult to machine using traditional techniques, which has impeded the development of MMCs. The use of traditional machinery to machine hard composite materials causes serious tool wear due to the abrasive nature of reinforcement. Many researchers have tried advanced machining methods to machine the MMCs and out of which wire electrical discharge machining (WEDM) emerged as an effective machining method [2]. WEDM shows higher capability for cutting complex shapes with high precision for these materials. Lokand Lee [3] compared the machining performance in terms of MRR and surface finish through observations obtained by processing of two advanced ceramics under different cutting conditions using WEDM. Rozenek et al. [4] used a metal matrix composite as workpiece material and investigated the variation of machining feed rate and surface roughness with machining parameters. In this study, SiC and Al_2O_3 particulate reinforced composites were machined by WEDM using one factor at a time strategy. The machining feed rate of WEDM on MMCs significantly depends on the kind of reinforcement. Tosun and Cogun [5] investigated the effect of machining parameters on wire wear ratio based on the weight loss of wire in WEDM and modeled statistically by using regression analysis techniques. Tosun *et al.* [6] introduced a statistical approach to determine the optimal machining parameters for minimum size of wire craters in WEDM. Yan *et al.* [7] used WEDM in the machining of Al_2O_3p/6061Al composite. The results show that the cutting speed, the surface roughness, and the width of slit of cutting test material significantly depend on the volume fraction of Al_2O_3 reinforcement particles. Manna and Bhattacharyya [8] used Taguchi L18 orthogonal array and Gauss elimination method for the parametric optimization of silicon carbide reinforced aluminium metal matrix composite. From experimental results and through ANOVA and F-tests values, the significant factors were determined for each machining performance criteria. Garg *et al.* [9] reviewed the research work in sinking EDM and WEDM on metal matrix composite materials. They found that most of the published work has been carried out in sinking EDM process. Not so much work has been reported on wire EDM. Patil and Brahmankar [10] analyzed the material removal rate in wire electro-discharge machining of silicon carbide particulate reinforced aluminium matrix composites and model was developed by using dimension analysis and non-linear estimation technique such as quasi-newton and simplex. The surface roughness of SiC reinforced aluminium was found superior to the unreinforced alloy. Patil and Brahmankar [11] experimentally analyzed the effect of electrical as well as non-electrical machining parameters on machining performance during WEDM of metal matrix composite (Al/Al_2O_3p). Volume fraction of reinforcement, current and on-time was found to have significant effect on cutting rate, surface finish and kerf width separately. The surface roughness of Al/Al_2O_3p was found inferior to the unreinforced alloy. This trend is completely opposite what was reported in the machining of Al/SiCp composite material by the same authors. Wire breakage was found to pose limitations on the material removal rate in the machining of MMCs. Wire shifting was found to deteriorate the machined surface. Pragya *et al.* [12] studied the effect of process parameters on wire breakage frequency and microstructure of cut surface during WEDC of SiCp/Al6061. It was found that surface roughness increases with the increase in percentage of SiC reinforcement. The findings are contrary to what was reported earlier by Patil and Brahmankar.

Literature review revealed that little work has been reported to analyze the influence of each parameter on machining performance including wire breakage separately, in machining of Al/SiCp-MMCs on WEDM using one factor at a time strategy. Moreover wire breakage were found to pose limitation on cutting speed in these materials but a very few work has been found that suggests the optimal range of parametric setting in which successful machining of Al/SiCp-MMCs is possible with minimum chances of wire breakage. The present work is therefore an attempt to experimentally analyze the effect of electrical as well as non electrical parameters on the response characteristics during machining of Al/SiCp-MMCs on WEDM. This work finds the suitable parametric range for which successful machining of these materials is possible with minimum chances of wire breakage.

II. Experimental Methodology

In the present study experiments were performed by using one factor at a time strategy. The objective of employing one factor at a time strategy was to understand the behavior of wire cut EDM process in machining of Al/SiCp-MMCs. In this strategy, a starting point or base line set of parameters are selected, then single parameter varied over its range while keeping other parameters fixed at their baseline level [13]. The objective of this workinvestigates the machining characteristics of MMCs material (i.e. Al/SiC/10% & Al/SiC/20%) and Al matrix material by Wire cut EDM process including cutting speed (mm^2/min), surface roughness (Ra, μm), spark gap (mm) and wire breakage. The six input parameters i.e. pulse on time (TON), pulse off time (TOFF), servo voltage (SV), peak current (IP), wire feed (WF) and wire tension (WT) are varied during the experimentation to investigate their effect on machining characteristics. This work also investigates the causes of wire breakage in machining of Al/SiCp-MMCs material on WEDM, analyzes it and suggests their remedial actions. Therefore, in this case uses greater discharge energy to facilitate wire breakage during WEDM.

A. Materials and Test Conditions

The experiments were conducted to cutsquare cross -section pieces of size 5 x 5mm and thickness, 15mm from the workpiece using four-axis ELECTRONICA SPRINTCUT CNC-wire cut EDM machine. Two types of Al based MMCs having 10 and 20% SiC particles (by weight) as reinforcement and Al matrix material itself as workpiece materials. The MMCs for the present investigation were made by stir casting. The stir casting method is widely used among the different processing techniques available [14]. Thickness of all pieces was kept constant as 15mm. Brass wire of 0.25mm diameter was used as wire electrode. The deionized water at temperature in the range 22– 25°C was used as dielectric fluid. The peak voltage (i.e. 100V), flushing pressure (i.e. 15kg/cm^2) and servo feed (i.e. 2100unit.) were kept at constant level during experimentation.

B. Module of Date Collection

The average cutting speed was calculated under each cutting condition by measuring the average total area cut by the wire electrode and the required cutting time. Next, surface roughness (Ra, μm) was measured by using Mitutoyo'ssurface roughness tester (S J 301). The surface roughness was shown by Ra value to quantitatively evaluate how WEDM parameters influence the surface roughness. The workpiece was machined at zero offset setting, hence the job become undersize. The actual size were measured using a TESAMASTER micrometer (least count = 0.001 mm). The spark gap (mm) was calculated from the relationship, as follow: 2 x spark gap + diameter of wire = desired size – actual size (measured). The control panel of machine display instant cutting speed, gap current and actual gap voltage.

III. Experimental Results and Analysis

A.Effect of Pulse On Time (TON)

Fig.1 plots the cutting speed verse the pulse on time for the Al (unreinforced) matrix material and two MMCs (i.e. Al/SiC/10% and Al/SiC/20%) by WEDM. These experimental results indicate that average cutting speed increases with the increase in pulse on time for all the three materials. This is because the discharge energy increases with the pulse on time leading to faster cutting speed. The cutting speed was found highest in Al matrix material at any value of pulse on time. Lower cutting speed in SiCp reinforced MMCs is attributed to lower electrical and thermal conductivities of these materials as compared to unreinforced Al matrix material. It was found that cutting speed was extremely low for pulse on time less than 0.3 µs for MMCs materials. The frequent wire breakage did not permit to cut the MMCs at higher level of Pulse on time i.e. beyond 1.4µs. The broken wire part was found to be almost burned for MMCs materials. Additionally, the frequency of wire breakage increases with the increase in the percentage fraction of SiCp at medium to higher level of pulse on time. However, the machining of Al matrix material did not exhibit wire breakage even at higher level of pulse on time.

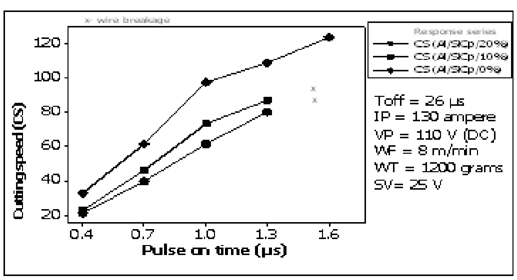

Fig.1 Scatterplot of Cutting speed vs. Pulse on time

Fig.2 plots the surface roughness against pulse on time for all three materials. This figure depicts that high level of pulse on time results in greater surface roughness. This is because of high discharge energy in the gap at higher pulse on time results increased depth of craters. However in machining of MMCs, the size of craters may not be the only reason of increased roughness. The plot shows that at higher pulse on time i.e. above 1µs, the surface roughness for MMCs have decreasing trend. Moreover, for the Al/SiCp/20% -MMC, it can be seen that machined surface roughness is worst. These results may be attributed to the fact that SiC particles on the machined surface have influence on the surface roughness. The surface roughness in machining of MMCs is determined by the protruding particles on the machined surface, depth made due to pullout of particles and due to depth of crater formed [11]. At lower discharge energy the influence of protruding particles is dominating results worst surface roughness for Al/SiCp/20%-MMC whereas at higher discharge energy the crater depth have dominating effect as protruding particles dislodged from the surface hence the surface roughness for MMCs have decreasing trend.

Fig.3 plots the spark gap verses pulse on time. The experimental results shown that spark gap increases with increasing pulse on time. The narrowest spark gap was obtained with Al/SiCp/20%-MMC material.

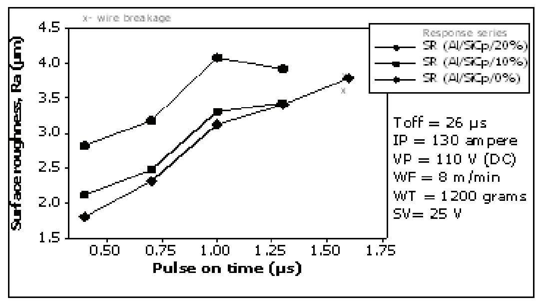

Fig.2 Scatterplot of Surface roughness vs. Pulse on time

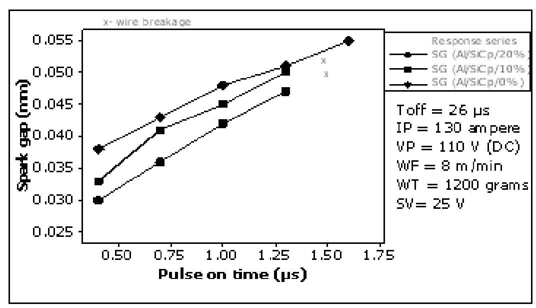

Fig.3 Scatterplot of Spark gap vs. Pulse on time

These results may be attributed to the fact that the spark gap depends upon discharge energy and thermal and electrical conductivity of the workpiece material. The thermal and electrical conductivity of MMCs material are lower than that of Al matrix material. This is because of reinforcement particles (SiCp) that have very high melting point and also act as insulator during machining, hence leading to the requirement of much more thermal energy per unit volume to melt MMC material.

B. Effect of Pulse Off Time (TOFF)

Fig. 4 plot pulse off time verses cutting speed, depicting that cutting rate decreases with the increase in pulse off time in a practically straight line fashion. Its effect on the cutting speed was as expected.

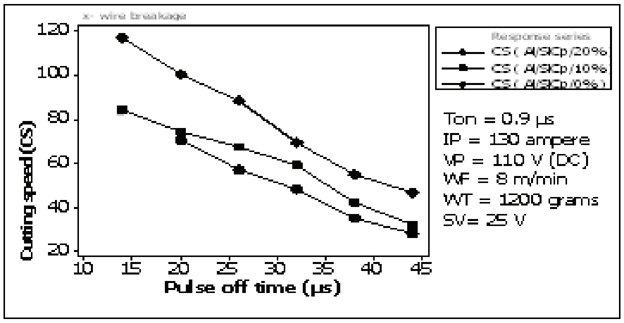

Fig.4 Scatterplot of Cutting speed vs. Pulse off time

It is attributed to the lower pulse frequency at high pulse off time. Too low pulse off time is not desirable as the ejected workpiece material will not be flushed away with the flow of the dielectric fluid and the dielectric fluid will not be deionized. Hence a minimum pulse off time is essential for deionization of the gap to avoid arching. The wire breakage did not permit to machine Al/SiCp/20%-MMC below 18µs pulse off time. The experimental results revealed that the wire breakage frequency during machining of MMCs significantly reduced with the increase in pulse off time. It was found that chances of wire breakage are very less when pulse off time set at or above 30µs for both MMCs.

Fig.5 plot shows the effect of pulse off time on surface roughness. From the graph it is evident that Al matrix material yielded the finest surface and the Al/SiCp/20%-MMC exhibited the roughest surface. The Ra value almost remained constant as pulse off time increased for MMCs and Al matrix material. This is because of that spark energy per pulse remain constant. The slightly decreasing trend with increase in pulse off time is attributed to better flushing of eroded materials by the dielectric fluid hence improve flushing efficiency. Fig.6 plot show the effect of pulse off time on spark gap. The experimental results revealed that spark gap almost remained constant but in wavy pattern as pulse off time increased. The Al/SiCp/20%-MMC material has narrowest spark gap as expected.

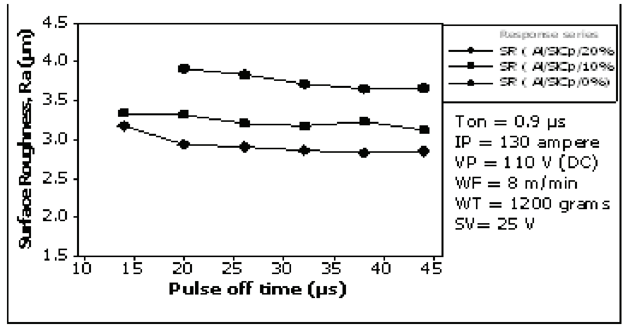

Fig.5 Scatterplot of Surface roughness vs. Pulse off time

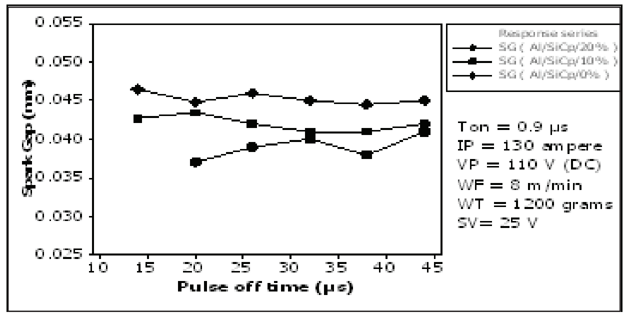

Fig.6 Scatterplot of Spark gap vs. Pulse off time

C.Effect of Spark Gap Set Voltage (SV)

The spark gap set voltage is a reference voltage for the actual gap voltage between the wire electrode and workpiece. Fluctuation of actual gap voltage within 10% of spark gap set voltage value can be considered as a stable machining [15]. In these experiments servo feed was also adjusted according to spark gap set voltage with stable actual gap voltage. Fig.7 plot cutting speed verse SV, depicting cutting speed increases significantly with the decrease in SGSV for MMCs and Al matrix material. The wire breakage did not permit to machine any material when SV less than 15V. The wire breakage was found maximum for Al/SiCp/20% MMC material at all setting of SV. The result may be attributed to the fact that too low value of SV results in small gap between wire electrode and workpiece. As a result ineffective flushing of molten metal contaminates the small gap and even results in arcing and subsequent wire breakage. The experimental results revealed that wire breakage significantly reduced with the increase in SV for MMCs materials.Fig.8 plot shows the effect of SV on surface roughness indicates that surface roughness decreases with the increase in SV. From the graph it is clear that its decrement slope of surface roughness is steeper from 20V to 30V and thereafter very less and almost constant for MMCs and Al matrix material. From Fig.9 it is clear that spark gap increases with the increase in SV for MMCs and Al matrix material as expected.

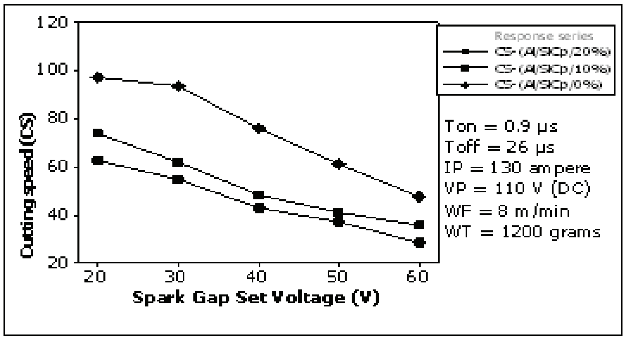

Fig.7 Scatterplot of Cutting speed vs. Spark gap set voltage

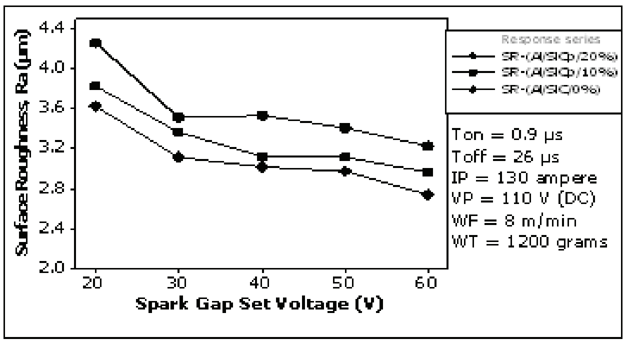

Fig.8 Scatterplot of Surface roughness vs. Spark gapvoltage

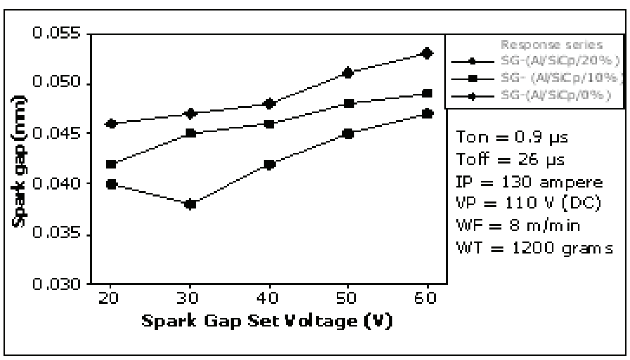

Fig.9 Scatterplot of Spark gap vs. Spark gap set voltage

D. Effect of Peak Current (IP)

Fig.10(a) shows the effect of peak current on cutting speed. It is clear from graph that cutting speed increases with increase in peak current for MMCs and Al matrix material. Fig.10(b) shows slightly increase in surface roughness for Al/SiCp-MMC material. Fig.10(c) depict that spark gap slightly increase in spark gap but in wavy pattern for Al/SiCp-MMC material. This is because of increase in pulse discharge energy with the peak current.

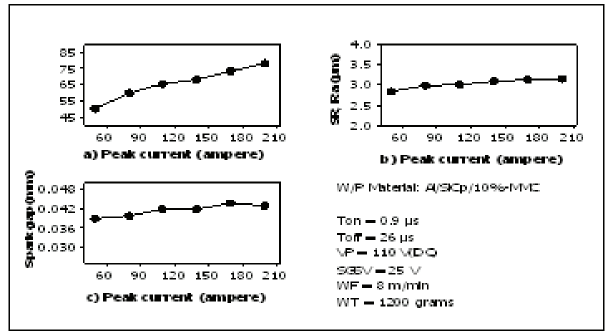

Fig.10 Scatterplot of Response characteristics vs. Peak current

E. Effect of Wire Feed (WF)

Fig.11 shows the response characteristics measured against different wire feed rate for Al/SiCp/10%-MMC material. From these figures it is clear that wire feed did not play a vital role during machining of MMCs on machining performance. Fig.11(c) depicts that the spark gap slightly decreases with the decrease in wire feed from 8m/min to 6m.min. However higher value of feed rate are required for working with higher pulse power. It was found that machining of MMCs materials are not possible with feed rate less than 5m/min. The wire breakage decreases with the increase in wire feed rate. To facilitate wire breakage discharge energy was increased with different wire feed rate. Fig.11(d) shows the effect of feed rate on maximum cutting speed for machining MMCs material. According to this figure, maximum cutting speed decreases from 84mm^2/min to 74mm^2/minwhen wire feed rate decreases from 10 to 6m/min for Al/SiCp/20% MMC material and similar effect for Al/SiCp/10% MMC material.

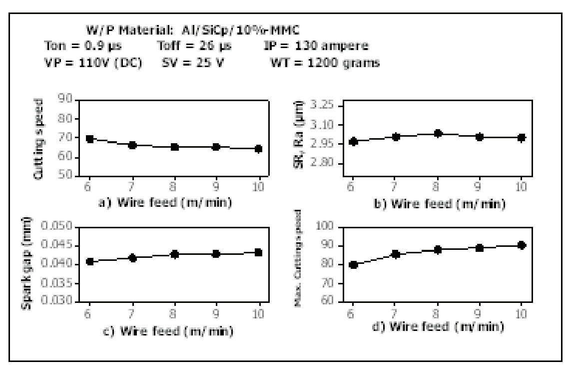

Fig.11 Scatterplot of Response characteristics vs. Wire feed

This effect is attributed to the fact that reducing the wire speed enables the brass wire to bear higher discharge energy per unit time, causing the wire to break. Moreover when fresh wire is supplied, greater is the conductivity resulted to stable machining without wire breakage.

F.Effect of Wire Tension (WT)

Fig.12 shows the effect of wire tension on surface roughness and spark gap for Al/SiCp/10%-MMC material. It was found that surface roughness and spark gap decreases with the increase in wire tension. This is because of that higher wire tension avoids the unintentional wire deflection from its straight path. The wire deflection is caused due to spark induced reaction forces and water pressure. Fig.12(c) shows the effect of wire tension on maximum cutting speed due to wire breakage. From the graph it is clear that maximum cutting speed decreases with the increase of wire tension for both MMCs materials. However, increasing wire tension from 800 to 1200grams has insignificant affects on the maximum cutting speed for both MMCs material. Hence the results demonstrate that the maximum cutting speed can be obtained when the wire tension is set below 1200grams.

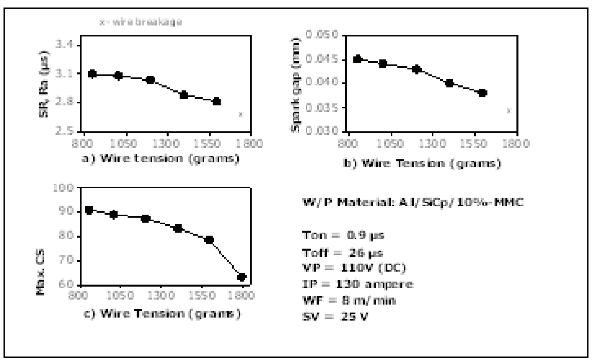

Fig.12 Scatterplot of Response characteristics vs. Wiretension

G. Effect of Flushing Pressure (WP)

The wire breakage did not allow cutting MMCs at low flushing pressure. The machining of MMCs was possible only at high flushing pressure i.e. 15 kg/cm^2. This is because of ineffective flushing of reinforced SiC particles and molten metal results contaminating the small gap, results in arcing and subsequent wire breakage [11]. Flushing efficiency in MMCs is adversely affected by the protruding SiC reinforced particles.

Table I shows the ranges of input machine parameters in which successful machining of Al/SiCp-MMCs on WEDM is found possible with minimum chances of wire breakages.

Table I Range of Machine Input Parameters For Stable Machining (Sprintcut Machine)

Input parameters	*Range*
Pulse on time (TON)	0.4-1 µs
Pulse off time (TOFF)	16-32 µs
Peak current (IP)	100-160 ampere
Wire feed (WF)	7-10 m/min
Wire tension (WT)	850-1200 grams
Spark gap voltage (SV)	20-40V
Flushing pressure (WP)	High (15kg/cm^2)

IV. Conclusions

a) Reinforcement percentage of SiC particles in MMCs were found to have significant effect on machining performance during wire cut EDM. Higher percentage of SiC reinforcement particles resulted into reduced cutting speed; deteriorate surface finish, increased frequency of wire breakage but narrow spark gap.

b) Pulse on time was found to be significant on cutting speed, surface roughness and spark gap. Increment of pulse on time resulted higher cutting speed, deteriorate surface finish and greater spark gap. But in case of Al/SiCp-MMCs materials it was found that surface roughness improved at higher setting (ie. >1µs) of pulse on time.

c) Pulse off time was found to be significant on cutting speed and wire breakage. Higher setting of pulse off time resulted lower cutting speed but significantly reduction of frequency of wire breakage.

d) SV was found significant on cutting speed and spark gap. Lower setting of SV resulted to higher cutting speed but greater spark gap.

e) Wire feed was found neutral parameter. However higher value of wire feed rate are required for working with higher pulse energy.

f) The surface roughness varies between 1.8-3.78 µm for the Al Matrix material. It was in the range of 2.12-3.43 µm and 2.82-4.2 µm for Al/SiCp/10%-MMC and Al/SiCp-MMC material respectively.

g) The spark gap was found to vary from 0.038-0.055mm in machining of Al matrix material. It was found to vary from 0.03-0.05mm and 0.028-0.047mm in the machining of Al/SiCp/10%-MMC and Al/SiCp/20%-MMC material.

h) Wire breakage could be reduced with high wire feed rate, a high flushing rate and setting of optimum wire tension.

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