

Taguchi Analysis of EDM Parameters on Surface Roughness of Al-SiC 6061 Metal Matrix Composite

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Abstract-Wire EDM process is a good method to machine extremely hard alloys, for example, the Al SiC metal matrix composites which are rated as one of the most commonly used metal matrix composites today. This research work studies important parameters in the wire electric discharge machining of Al SiC 6061 metal matrix composite. The MMC specimens studied in this research work were fabricated with the stir casting process. Taguchi approach was employed to study the machining parameters during the machining process and to minimize the surface roughness values of the surfaces obtained by wire EDM machining. It was found out that out of the seven factors used in this study, gap voltage is the most prominent factor which influences the obtained surface roughness values. Comparatively, a very low value of surface roughness (R_q) was obtained during confirmation test.

Keywords-Wire EDM; Composites; Al SiC; 6061; MMC; Surface Roughness; Taguchi; Orthogonal Arrays

1. INTRODUCTION

There are a total of seven main factors that influence the surface roughness value of a surface during the machining done by wire EDM process. These factors have been studied in this research work, six out of which are namely the nozzle workpiece distance, the wire feed rate at which the machining wire approaches the workpiece in order to machine it, the machining current which is made to pass through the wire and workpiece gap, the gap voltage generated between the wire and the workpiece, the wire tension of the machining wire, and the dielectric flow rate at which the dielectric is incident upon the machined area of the workpiece from the upper nozzle. Amongst these six factors, the first two factors have been studied at two levels, and the remaining four factors have been studied at four levels each. The Al SiC 6061 MMC that has been used in this work is a metal matrix composite (MMC) in which SiC particles have been used as a reinforcement phase. The percentage of SiC particles has also been studied at two levels of 5% and 10% SiC as the work piece composition, totalling the number of factors studied as seven.

Design of experiments in this work have been done in accordance with the Taguchi technique which makes use of Orthogonal Arrays. The most favourable levels of each of the abovementioned seven factors have been found out. Confirmatory test results have been conducted, and the analysis of results has also been done.

1.1. The Wire EDM

Since a long time ago, researchers have attempted to employ non-conventional machining processes such as EDM, WEDM, and AWJM which are used for machining hard and high strength alloys [1]. The origin of electrical discharge machining goes back to 1770 when English scientist Joseph Priestly discovered the erosive effect of electrical discharges on metals [2]. In a Wire Electrical Discharge Machining (WEDM), the tool electrode is a continuously moving conductive wire over an electrically conducting workpiece. The practical technology of the WEDM process is based on the conventional EDM sparking phenomenon utilising the widely accepted non-contact technique of material removal [3]. Functions like wire feed, table movement, dielectric circulation and power can all be controlled through a keyboard. The mechanism of metal removal in Wire Electrical Discharge Machining involves the complex erosion effect from electric sparks generated by a pulsating direct current supply generated between the conductive wire and the work piece. Water is usually used as a dielectric in WEDM. Water is advantageous as a dielectric in this process because of its less viscosity and rapid cooling rate.

The wire EDM machine used for this work was Electra Supercut. This machine uses a brass wire of diameter 0.2 mm as cutting wire and deionized water as dielectric which is continuously circulated through the machine and filtration unit in a closed circuit.

1.2. Metal Matrix Composite Al Sic 6061

Metal matrix composites (MMCs) generally consist of lightweight metal alloys of aluminium, magnesium, or titanium, reinforced with ceramic particulate, whiskers, or fibres. The reinforcement is very important in an MMC because it determines its mechanical properties, cost, and performance. Compared with the unreinforced metal, MMCs have significantly greater stiffness and strength. However, these properties are obtained at the cost of lower ductility and toughness [4].

The aluminium industry has evolved over the past 100 years (i.e. year 1900 onwards) from the limited production of alloys and products to the high-volume manufacturing of a wide variety of products. Later, the introduction of alloy aluminium 6061 (also known as 61S) in 1935 filled the need for medium-strength, heat-treatable products with good corrosion resistance which could be welded or anodized. Alloy 6061 evolved after its initial development, the corrosion resistance of alloy 6061 even after being welded made it popular in early railroad and marine applications, and it is still used for a variety of products. The ease of hot working and low quench sensitivity are advantages in forged automotive and truck wheels. Unlike the harder aluminium-copper alloys, 6061 components can be easily fabricated by extrusion, rolling, or forging. Also made from alloy 6061 are structural sheets and tooling plates produced for the flat-rolled products market, extruded structural shapes, rods, bars, tubings, automotive drive shafts, and aircraft structures.

The Al SiC 6061 Metal Matrix Composite (MMC) used in this research work has the alloy of aluminium 6061 as its matrix phase and particles of SiC with 220 mesh size as its reinforcement phase. The two variations studied in this work are those of 5% SiC and of 10% SiC compositions, respectively. The specimens used in this work had been prepared by the stir casting process.

2. PREPARATION OF THE SPECIMENS

In order to confirm the composition of the aluminium 6061 alloy, its spectrometry test was carried out as per the ASTM E1251-2011 test method. Two square prisms had been cut from the alloy piece for this purpose on a wire EDM machine, as have been depicted in Figure 1.



Fig. 1. Two square prisms were taken from the aluminium 6061 alloy piece in order to carry out spectrometry analysis.

The results were tallied with the available data of Al 6061 alloy's chemical composition, after which, this alloy piece was used for preparation of Al SiC 6061 specimens by the stir casting process. The results of this test have been shown in Table 1.

Table 1. Spectrometry test results of aluminium 6061 alloy.

Element	Cu	Mg	Si	Fe	Ni	Mn
Value	0.203	0.933	0.784	0.304	0.003	0.083
(%)	0	0	0	0	2	6
Element	Zn	Pb	Sn	Ti	Cr	Al
Value	0.056	0.027	<	0.068	0.047	Rem.
(%)	1	0	0.010	9	2	0

In the specimen preparation stage, the aluminium 6061 alloy piece which was taken as the matrix phase was cut into smaller blocks so as to facilitate melting in a vertical muffle furnace. SiC powder of 220 mesh size had been taken as the reinforcement phase. Both of them had been accurately weighed for the 5% and 10% composition specimens, respectively. Also, a magnesium ribbon strip was added which had been 1% by weight of alloy. The aluminium 6061 blocks, the SiC powder, and the magnesium wire used for the preparation of specimens have been shown in Figure 2.



Fig. 2. The ingredients for making the specimens which were used in this study. The aluminium 6061 blocks, the magnesium wire, and the SiC particles have been placed left to right in their respective order.

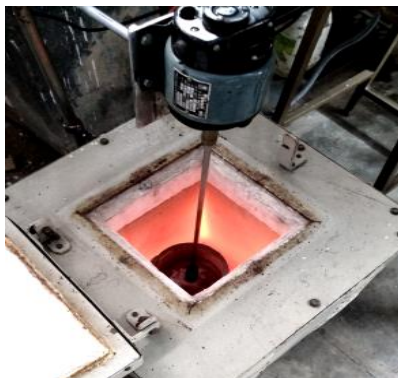
During casting, accurately weighed aluminium 6061 blocks were placed in a crucible and heated to a temperature of about 850°C. Preheating of reinforcement results in uniform distribution and better mechanical properties [5]. SiC particles are preheated in this process so as to expel moisture and other volatile contaminants from them. An accurately weighed quantity of magnesium ribbon to the hot crucible was then done which was slightly problematic as it caught fire on incident to furnace heat but was immediately sunk in the molten slurry with an m.s. rod (the operators had previous experience of doing so). An electrical motor operated stirrer of graphite was then left to rotate in it for some time, as shown in Figure 3.

Fig. 3. A stirrer of graphite was used to rotate the liquefied contents of the crucible placed in the furnace. The molten metal was then poured into two specially prepared cylinder moulds, as shown in Figure 4.



Fig. 4. Some slag that had been floating on the molten metal was removed with an m.s. rod, and the remaining molten metal was poured in specially made cylinder moulds.

After allowing to cool down and solidify for some time, the first solidified casting was removed from its cylinder mould. The process was repeated for the other casting, giving two castings, the one with 5% SiC content composition and the other one with 10%



SiC content composition, respectively. The surfaces of these castings were pitted and had been having inaccurate dimensions at that time. Hence, they were turned on a lathe. These specimens have been shown in Figure 5.

Fig. 5. The two castings after being turned to accurate dimensions of 14 mm diameter.

This SEM analysis of one of these specimens was done on a Scanning Electron Microscope of JEOL make whose results have been shown in Figure 6.

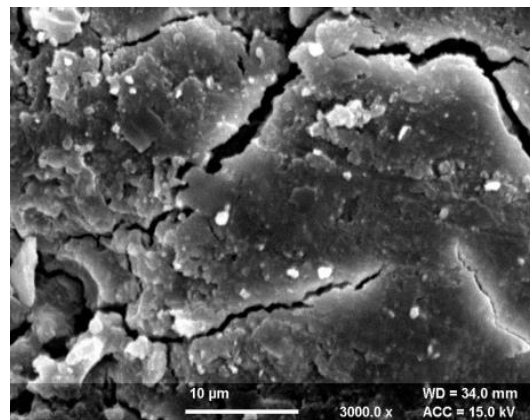


Fig. 6. SEM photograph of the specimen.

3. DESIGN OF EXPERIMENTS

Experiment is defined as a test to establish a hypothesis. To design an experiment is to develop a scheme or layout of the different conditions to be studied. Design of Experiments is another name given to Factorial Experiments that involve more than one



factor at two or more levels. Factor here is the name given to every individual variable.

An experimental design should satisfy two objectives. Firstly, the number of trials should be minimum, and



secondly, conditions of each trial must be specified. Taguchi design of experiments is such an efficient test strategy that possesses some advantages because of a balanced arrangement [6].

3.1. The Taguchi technique and the Orthogonal arrays

The Taguchi technique makes use of Orthogonal Arrays (OAs). An OA is a mathematical invention recorded by Jacques Hadamard, a French mathematician in as early as 1897 [6]. The use of Latin squares Orthogonal Arrays (a type of Orthogonal Array).

The Taguchi technique of layout of the conditions (Design of Experiments) involving multiple factors was first proposed by the Englishman Sir RA Fischer in the 1920s. This method is popularly known as the Factorial Design of Experiments. It may either be a *Full* Factorial Design or else a *Fractional* Factorial Design. A Full Factorial Design identifies all possible combinations for a given set of factors. In a Full Factorial Design, seven factors, each at two levels shall need $2^7 = 128$ experiments. In order to reduce such a large number of experiments to a practical level, only a small set from all the possibilities is selected in the Fractional Factorial Design. This is done with the use of Orthogonal Arrays. An Orthogonal Matrix Array, also called the Orthogonal Array, abbreviated as OA is defined as such a Fractional Factorial Matrix that it assumes a balanced, fair comparison of levels of any factor in which all columns can be evaluated independently of one another [6].

The term levels of various factors is defined as the setting of various factors in a factorial experiment [6]. It is generally considered wise to think the level 1 is lesser in numerical value than level 2; both levels of a factor should have the same units. It can be seen that Taguchi method has been successfully used in the optimization of machining parameters [7]. In fact, optimization of process parameters is the key step in the Taguchi method in achieving high quality without increasing the cost [8].

4. CONDUCTING THE EXPERIMENTS

After the design of experiments, when each experimental run was decided in terms of various parameters and their levels, the specimens were mounted on the wire EDM machine, and machining cuts were performed (48 in number) in accordance to the conditions described by the 1-16 orthogonal array (pronounced as *ell sixteen*). Each of these cuts was 14 mm deep and all these cuts were placed mutually at an axial distance of 2.5 mm. The machining of such cuts on cylindrical specimens gave semi circular shaped pieces, one of which is shown in Figure 7. During experimentation, after machining each cut, the machining parameter levels were changed every time as per the Taguchi design of experiments and the next cut was then machined in the specimen. Machining cuts were performed on both the specimens, as per the design of experiments. After machining all the cuts on both the specimens, surface roughness testing was carried out on the machined surfaces brought out by the machining cuts. In order to get more accurate results, surface roughness measurement was done at five places on each machined surface, and their average was then taken. A Mitutoyo make surfest meter SJ-201-P was used for this purpose, and roughness of machined surfaces was measured in units of μm on the scale of R_q . This has been shown in Figure 7 below.

Fig. 7. Photograph of the roughness testing of one of the semi circular shaped pieces being carried out.

The Taguchi 1-16 orthogonal array that we have used in this work directs to use 16 experimental trials. For the sake of accuracy, each of these tests had been performed 3 times, because of that, the total number of tests came out to be 48. This was done in accordance to the concept of repetition. After obtaining the surface roughness values of 48 semi circular pieces, the average surface roughness values were found out by taking average. These are the 16 settings that have been directed by the 1-16 orthogonal array in accordance to which these 48 tests had been performed. Table 2 shows these 16 values.

Table 2. Average surface roughness obtained during machining at each setting of Orthogonal Array (numbered 1 to 16).

Number of cut	Surface roughness values of specimen pieces (numbered 1 to 16) (μm)	Surface roughness values of specimen pieces (numbered 17 to 32) (μm)	Surface roughness values of specimen pieces (numbered 33 to 48) (μm)	Average surface roughness (OA settings of 1 to 16) (μm)
1	6.78	4.87	4.85	5.5
2	4.2	5.88	4.93	5
3	6.75	7.47	6.26	6.83
4	6.48	8.33	8.58	7.8
5	4.86	4.61	4.45	4.64
6	3.97	6.17	4.09	4.74
7	4.53	5.32	4.66	4.84
8	8.09	6.66	6.21	6.99
9	4.96	5.4	3.76	4.71
10	7.5	4.59	4.15	5.41
11	4.54	6.82	5.02	5.46
12	7.23	6.6	7.27	7.03
13	4.51	4.05	4.53	4.36
14	5.8	4.48	4.25	4.84
15	5.15	4.83	3.91	4.63
16	7.71	6.12	4.89	6.24

As per the standard method of Taguchi analysis of orthogonal arrays, these 16 values had been placed on the right side of the 1-16 orthogonal array, as shown in Table 3 below.

Table 3. Orthogonal Array 1-16 for surface roughness.

Level 4	1. 25 A	72 V	12 00 g	2. 5 lp .m
Lev	1.	68	11	2.

Level 3	10 % Si C	50 mm	5 m/min	0.75 A	64 V	100 g	1.5 lp .m	
Level 2	5 % Si C	40 mm	3 m/min	0.50 A	60 V	90 g	1.0 lp .m	
Level 1	Work piece composition	Nozzle or orifice distance	Wire feed rate	Machining Current	Gap voltage	Wire tension	Dielectric flow rate	
Experimental no.	Factor A	Factor B	Factor C	Factor D	Factor E	Factor F	Factor G	Average surface roughness (μm)
1	1	1	1	1	1	1	1	5.5
2	1	2	2	1	2	2	2	5
3	2	1	2	1	3	3	3	6.83
4	2	2	1	1	4	4	4	7.8
5	2	2	1	2	1	2	1	4.64
6	2	1	2	2	2	1	2	4.74
7	1	2	2	2	3	4	4	4.84
8	1	1	1	2	4	3	3	6.99
9	1	2	2	3	1	3	4	4.71
10	1	1	1	3	2	4	3	5.41
11	2	2	1	3	3	1	2	5.46
12	2	1	2	3	4	2	1	7.03
13	2	1	2	4	1	4	2	4.36
14	2	2	1	4	2	3	1	4.84
15	1	1	1	4	3	2	4	4.63
16	1	2	2	4	4	1	3	6.24

As per the standard method of Taguchi analysis of orthogonal arrays, these 16 values had been placed on the right side of the 1-16 orthogonal array.

5. ANALYSIS OF RESULTS

5.1. Calculations for the Average Effects of surface roughness

The calculations of the Average Effects of various parameters affecting surface roughness have been shown below at various levels.

The Average Effects of Work piece composition,

$$A_1 = (5.5+5+4.84+6.99+4.71+5.41+4.63+6.24)/8 = 5.415,$$

$$A_2 = (6.83+7.8+4.64+4.74+5.46+7.03+4.36+4.84)/8 = 5.713.$$

The Average Effects of Nozzle workpiece distance,

$$B_1 = (5.5+6.83+4.74+6.99+5.41+7.03+4.36+4.63)/8 = 5.686,$$

$$B_2 = (5+7.8+4.64+4.84+4.71+5.46+4.84+6.24)/8 = 5.441.$$

The Average Effects of Wire feed rate,

$$C_1 = (5.5+7.8+4.64+6.99+5.41+5.46+4.84+4.63)/8 = 5.659,$$

$$C_2 = (5+6.83+4.74+4.84+4.71+7.03+4.36+6.24)/8 = 5.469.$$

The Average Effects of Machining Current,

$$D_1 = (5.5+5+6.83+7.8)/4 = 6.282,$$

$$D_2 = (4.64+4.74+4.84+6.99)/4 = 5.303,$$

$$D_3 = (4.71+5.41+5.46+7.03)/4 = 5.653,$$

$$D_4 = (4.36+4.84+4.63+6.24)/4 = 5.018.$$

The Average Effects of Gap voltage,

$$E_1 = (5.5+4.64+4.71+4.36)/4 = 4.803,$$

$$E_2 = (5+4.74+5.41+4.84)/4 = 4.998,$$

$$E_3 = (6.83+6.84+5.46+4.63)/4 = 5.440,$$

$$E_4 = (7.8+6.99+7.03+6.24)/4 = 7.015.$$

The Average Effects of Wire tension,

$$F_1 = (5.5+4.74+5.46+6.24)/4 = 5.485,$$

$$F_2 = (5+4.64+7.03+4.63)/4 = 5.325,$$

$$F_3 = (6.83+6.99+4.71+4.84)/4 = 5.843,$$

$$F_4 = (7.8+4.84+5.41+4.36)/4$$

$$= 5.603.$$

The Average Effects of Dielectric flow rate,

$$G_1 = (5.5+4.64+7.03+4.84)/4 = 5.503,$$

$$G_2 = (5+4.74+5.46+4.36)/4 = 4.890,$$

$$G_3 = (6.83+6.99+5.41+6.24)/4 = 6.368,$$

$$G_4 = (7.8+4.84+4.71+4.63)/4 = 5.495.$$

These Average Effects have been shown in Table 4.

Table 4. The Average Effects of various factors affecting surface roughness in Wire EDM process.

Factor	Factor description	Level 1, L1	Level 2, L2	Level 3, L3	Level 4, L4
A	Work piece composition	5.4	5.7	-	-
B	Nozzle workpiece distance	5.6	5.441	-	-
C	Wire feed rate	5.6	5.4	-	-
D	Machining Current	6.2	5.3	5.6	5.018
E	Gap voltage	4.8	4.9	5.4	7.015
F	Wire tension	5.4	5.3	5.8	5.603
G	Dielectric flow rate	5.5	4.8	6.3	5.495

5.2. Calculations for sum of squares of factors and their percentage contribution

Based on the Table 4 given above, next, the sum of square of each factor was calculated. The relation used here is shown in Eq. (1),

$$SS = \frac{\sum x - x_m^2}{n - 1} \tag{1}$$

where all terms have their usual notations.

Table 5.1. Calculating Means of levels

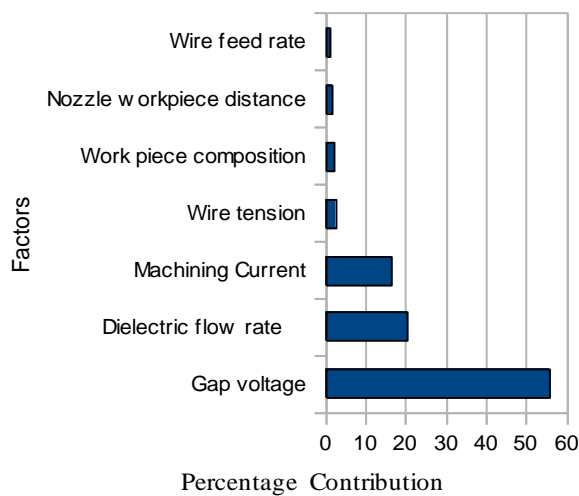
Factor	Factor description	Level 1, L1	Level 2, L2	Level 3, L3	Level 4, L4	Mean of Levels (x _m)
A	Work piece	5.4	5.7	-	-	5.56
		2	1			

	composition					
B	Nozzle workpiece distance	5.69	5.44	-	-	5.56
C	Wire feed rate	5.66	5.47	-	-	5.56
D	Machining Current	6.28	5.3	5.65	5.02	5.56
E	Gap voltage	4.8	5	5.44	7.02	5.56
F	Wire tension	5.49	5.33	5.84	5.6	5.56
G	Dielectric flow rate	5.5	4.89	6.37	5.5	5.56

The Means of Levels of various factors are then used to find out the Percentage Contribution of each factor, as shown in Table 5.2 and Table 5.3.

Table 5.2. Calculating Σ for Percentage Contribution

Factor	Factor description	(L1 \bar{x}_m) ²	(L2 \bar{x}_m) ²	(L3 \bar{x}_m) ²	(L4 \bar{x}_m) ²	Σ
A	Work piece composition	0.022201	0.022201	-	-	0.044402
B	Nozzle workpiece distance	0.15006	0.15006	-	-	0.030013
C	Wire feed rate	0.09025	0.09025	-	-	0.018050



D	Machining Current	0.515524	0.068121	0.007921	0.298116	0.889682
E	Gap voltage	0.579121	0.320356	0.015376	2.105401	3.020254
F	Wire tension	0.006241	0.057121	0.077841	0.01521	0.142724
G	Dielectric flow rate	0.003721	0.454276	0.646416	0.004761	1.109174

Table 5.3. Calculations for Percentage contribution

Factor	Σ	D.F.	Sum of squares	Contribution	Contribution (%)
A	0.044402	1	0.044402	0.0245	2.45
B	0.030013	1	0.030013	0.0166	1.66
C	0.018050	1	0.018050	0.0100	1
D	0.889682	3	0.296561	0.1636	16.36
E	3.020254	3	1.006751	0.5553	55.53
F	0.142724	3	0.047575	0.0262	2.62
G	1.109174	3	0.369725	0.2039	20.39

The percentage contribution of all these factors have been shown in Figure 8. It is clearly seen that Gap Voltage has maximum effect on the surface roughness values, followed by Dielectric flow rate and machining current, respectively.

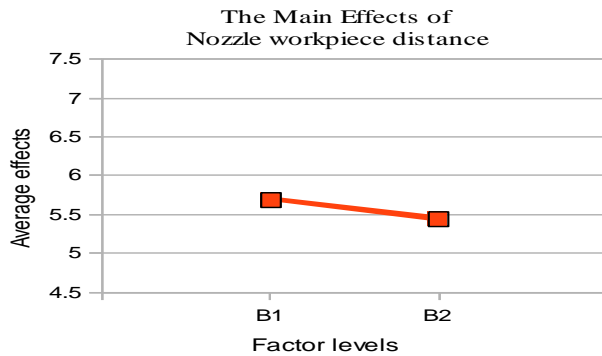
Fig. 8. Percentage contribution of various factors in wire EDM machining of Al SiC 6061 MMC.

5.2. Calculations for Main Effects of surface roughness

In order to calculate the Main Effects of various parameters affecting surface roughness, the Average Effects of each factor are plotted on a graph, one by one. This is done by placing the Average Effects along the x-axis and the factor levels along the y-axis of all the factors. The plots obtained have been shown below.

5.3.1. Main Effects of the factor of workpiece composition

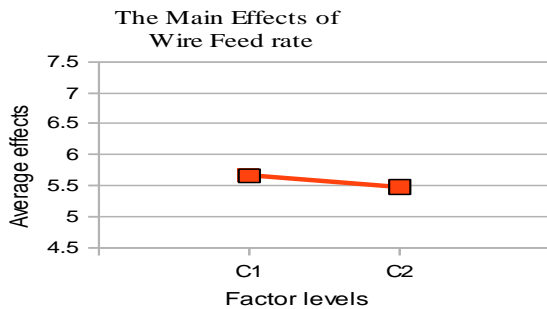
Fig. 9. A graphical plot showing the Main Effects of



factor A (the percentage of SiC in Al SiC MMC specimens). X axis has 5% SiC composition as A1 and 10% SiC composition as A2 whereas Y axis shows Average Effects in units of R_q .

The surface roughness value needs to be minimized. Hence, from Figure 9, we see that the factor level that shall result in minimum value of surface roughness corresponds to A1.

5.3.2. Main Effects of the factor of Nozzle workpiece



distance

Fig. 10. A graphical plot showing the Main Effects of factor B (Nozzle workpiece distance). Y axis has Average Effects in units of R_q . X axis has 40 mm as level B1 and 50 mm as level B2 in units of mm.

The value of surface roughness needs to be minimized. Hence, from Figure 10, we see that the factor level that shall result in minimum value of surface roughness corresponds to B2.

5.3.3. Main Effects of the factor of wire feed rate

Fig. 11. A graphical plot showing the Main Effects of factor C (Wire feed rate). Y axis has Average Effects in units of R_q . X axis has 3 m/min as level C1 and 5 m/min as level C2.

The value of surface roughness needs to be minimized. Hence, from Figure 11, we see that the factor level which shall result in minimum value of surface roughness corresponds to C2.

5.3.4. Main Effects of the factor of Machining current

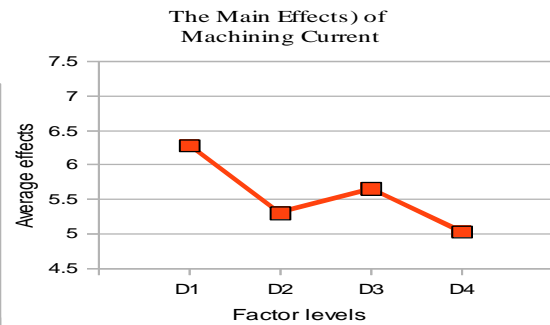
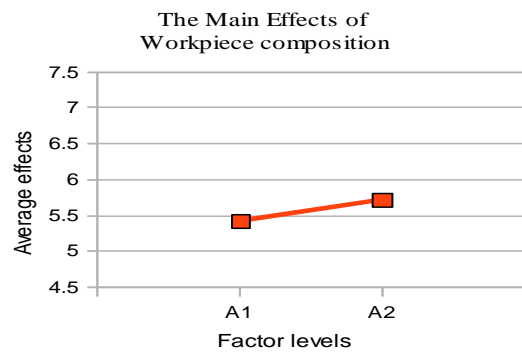
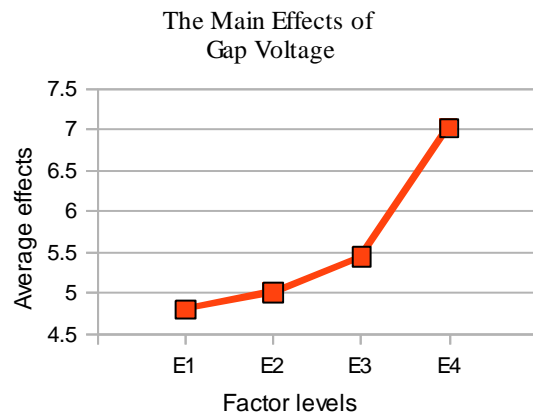


Fig. 12. A graphical plot showing the Main Effects of



factor D (machining current). Y axis has Average Effects in units of R_q . X axis has machining current as



a factor at levels D1, D2, D3, and D4 in units of ampere.

The value of surface roughness needs to be minimized. Hence, from Figure 12, we see that the factor level which shall result in minimum value of surface roughness corresponds to D4.

5.3.5. Main Effects of the factor of gap voltage

Fig. 13. A graphical plot showing the Main Effects of factor E (gap voltage). Y axis has Average Effects in

units of R_q . X axis has gap voltage as a factor at levels E1, E2, E3, and E4 in units of volts.

The value of surface roughness needs to be minimized. Hence, from Figure 13, we see that the factor level which shall result in minimum value of surface roughness corresponds to E1.

5.3.6. Main Effects of the factor of wire tension

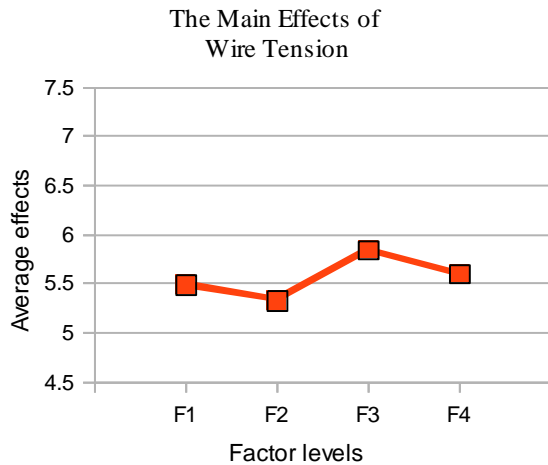


Fig. 14. A graphical plot showing the Main Effects of factor F (wire tension). Y axis has Average Effects in units of R_q and X axis has (wire) tension as a factor at levels F1, F2, F3, and F4 in units of grams.

The value of surface roughness needs to be minimized. Hence, from Figure 14, we see that the factor level which shall result in minimum value of surface roughness corresponds to F2.

5.3.7. Main Effects of the factor of dielectric flow rate

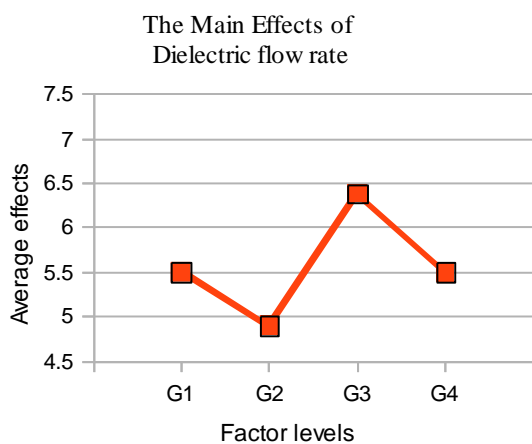


Fig. 15. A graphical plot showing the Main Effects of factor G (dielectric flow rate). Y axis has Average Effects in units of R_q . X axis has dielectric flow rate as a factor at levels G1, G2, G3, and G4 in units of l.p.m.

The value of surface roughness needs to be minimized. Hence, from Figure 15, we see that the factor level which shall result in minimum value of surface roughness corresponds to G2.

From the graphical plots shown above, we see that the levels of various factors which shall result in a low value of surface roughness corresponds to $A_1B_2C_2D_4E_1F_2G_2$.

The levels of various factors that shall result in minimum value of surface roughness can be shown in tabular form, as in Table 6.

Table 6. Levels of factors for minimum value of surface roughness.

Factor	Factor Description	Levels for minimum surface roughness
A	Work piece composition	SiC 5%
B	Nozzle workpiece distance	50 mm
C	Wire feed rate	5 m/min
D	Machining Current	1.25 A
E	Gap voltage	60 V
F	Wire tension	1000 g
G	Dielectric flow rate	1.5 l.p.m.

It is deemed that the above mentioned levels of the given factors which shall result in minimum value of surface roughness.

5.3. Calculations for Projection of optimal performance

According to the usual notations, here,

Total number of observations, $N = 16$

Sum total of all observations, T

$$= 5.5 + 5 + 6.83 + 7.8 + 4.64 + 4.74 + 4.84 + 6.99 + 4.71 + 5.41 + 5.46 + 7.03 + 4.36 + 4.84 + 4.63 + 6.24 = 89.02.$$

Using the relation for optimal performance,

$$Y_{\text{optimal}} = T/N + (A_1 - T/N) + (B_2 - T/N) + (C_2 - T/N) + (D_4 - T/N) + (E_1 - T/N) + (F_2 - T/N) + (G_2 - T/N)$$

$$= 5.56 + (5.42 - 5.56) + (5.44 - 5.56) + (5.47 - 5.56) + (5.02 - 5.56) + (4.8 - 5.56) + (5.33 - 5.56) + (4.89 - 5.56)$$

$$= 5.56 + (-0.14) + (-0.12) + (-0.09) + (-0.54) + (-0.76) + (-0.23) + (-0.67)$$

$$= 3.01 \mu\text{m}.$$

6. CONFIRMATION TESTS

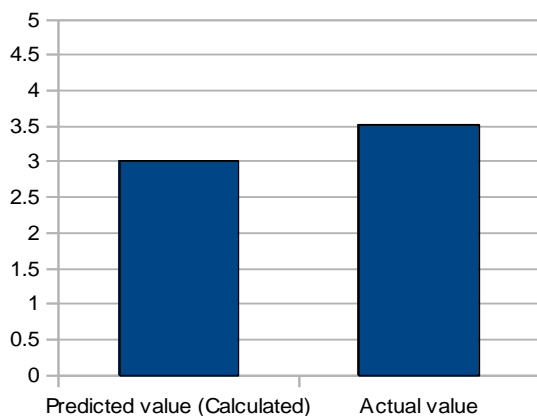
In order to confirm the accuracy of predicted values, a total of three tests were performed and hence, three specimen pieces were obtained by wire EDM machining at the experimental factors which have been described in Table 6. Surface roughness values were measured on all these three specimen pieces at five random points on their surfaces and their average was taken. Then the average surface roughness values of these three specimen pieces were taken. These calculations have been shown in Table 7.

Table 7. Confirmation test results for surface roughness

Specimen piece no.	Measured values (μm)					Mean values (μm)	Average value (μm)
	1 st	2 nd	3 rd	4 th	5 th		
1	4.16	3.51	3.18	3.73	3.42	3.6	3.52
2	3.21	2.85	3.35	3.83	3.88	3.41	
3	3.42	3.11	3.61	3.51	3.54	3.54	

The value of average surface roughness obtained during confirmation tests was compared with the values earlier obtained using the relation for optimal performance. Actual values were 116.94% of the calculated values which are quite satisfactory. Their comparison has been shown graphically in Figure 16.

Fig. 16. Comparison of predicted values which had



been obtained theoretically by mathematical relations with those obtained during the confirmation tests.

7. CONCLUSIONS

High energy material removal methods allow the machining process to take a major leap to increase the removal rate. However, these methods also have a significant impact on the part integrity as they alter the state of the surface after processing by the introduction of defects or surface residuals, generate unfavourable tensile residual stresses or influence the surface roughness [9]. In this work, it became evident that various factors affect the surface roughness of machined surfaces of Al SiC 6061 MMC done by wire EDM machine. This work shows that how seven of these factors, namely, workpiece composition, nozzle workpiece distance, wire feed rate, machining current, gap voltage, wire tension, and dielectric flow rate, can be used to control the roughness values of surfaces being machined. As one of these factors is work piece composition, we also found out the composition of workpiece which shall result in a better value of surface roughness.

The percentage contribution of these factors also had been worked out, which gave the gap voltage as the most dominant factor affecting the surface roughness values.

The predicted values which were obtained by relations in a theoretical way were very close to the values obtained during the confirmation tests which authenticates this research work.

This study shows the way to obtain better surfaces, having lesser values of surface roughness which are desirable for use in numerous mechanical processes.

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