Experimental Investigation of Wire EDM Process Parameters on SiC Particles Reinforced AA6063 (Black & Green) Aluminium Alloy Matrix Composites

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Abstract

The wire electrical discharge machining (WEDM) process contains a large number of variables that affect its performance like surface roughness (SR) and metal removal rate (MRR). In this study, to optimize the cutting conditions of WEDM on AA6063 aluminum and alloy reinforced with black and green bonded silicon carbide of size 25µm (10 % volume fraction). The brass wire with the diameter of 0.25 mm has been used as the wire electrode. The effect of various process parameters of metal matrix composite such as pulse on time, wire feed and gap voltage. After machining the surface roughness is measured using surface roughness tester, scanning electron microscope (SEM) and Energy dispersive X-ray spectrum. The experimental results, showed that the combination of pulse on time, wire feed and gap voltage is essential to achieve effect of maximum material removal rate and minimization of surface roughness. The regression analysis shows that the pulse on time, wire feed and gap voltage are the input parameters and are significant effect of AA6063/SiC to provide the basic technological information used for industrial users.

Keywords: *Wire EDM, Surface Roughness, MRR, ANNOVA, Regression Analysis*

1. Introduction

The high demand of new and improved metal matrix composites (MMCs) using aerospace, automotive industries for better overall performance for achieving an enhancement in stiffness, realization of high strength to weight ratio and an improvement in wear resistance, In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. Numerous aspects are to be considered with regard to the metallic matrix, namely, composition, response to heat treatments, mechanical and corrosion behavior. Wire-EDM is recent electro-thermal metal removal process which has been used to machine irregular shapes in machines and also an electrically conductive materials.

In the WEDM of drilling metal matrix composites of type LM25-based aluminium alloy reinforced with green bonded silicon carbide has expected the correlation between cutting speed, feed, point angle the specific cutting pressure [1]. The observed process parameters of machining Titanium alloy by Wire-EDM that the result shows pulse on time and pulse off time are the important parameters that influences the surface roughness whereas the pulse off time has major influence on material removal rate [2]. The wire-EDM process parameters of ballistic grade aluminium alloy have been performed with four machining variables: pulse-on time, pulse-off time, peak current and spark voltage. The result showed that pulse-on time, peak current and spark voltage were significant variables [3]. The experimental analysis of Wire EDM on Aluminium HE30 and showed that the combination of pulse on time, pulse off time, wire tension, lower flush, wire tension and upper flush is essential to attain maximization of material removal rate and minimization of surface roughness and kerf width [4]. The experimental investigation of wire EDM on aluminium and mild steel has been done and shows that in case of kerf width, wire feed rate and spark on time have significant effect on aluminium and mild steel respectively [5].

Some methods have been employed to measure the surface roughness of the hole after drilling of the materials, [6-14]. ANNOVA and Regression analysis is clearly one of the most important tools available to the researchers. The main objectives of the regression analysis is to express the response variable as a function of the predictor variables. The duality of fit and the accuracy of conclusion depend on the data used. Hence unacceptably collected data result in poor fits and conclusions.

In this paper the process parameters of the metal matrix composites and the surfaces of the holes are analyses by using ANNOVA and regression analysis. In which the specific process parameter was to make the hole at better surface finish involves using the analysis.

2. Experimental Techniques

2.1. Preparation of Composites

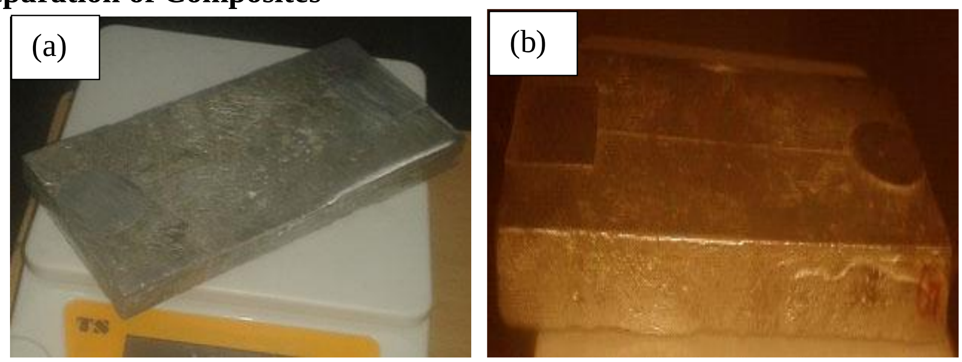

Figure 1. The various compositions of the prepared composites (a) Aluminum with 10 % SiC-B (b) Aluminum with 10% SiC-G

In this work, 10 % SiC were die casted, using reinforcement materials of AA6063 aluminum alloy and silicon carbide particles of average size 25 micron. The aluminum was melted in a graphite crucible at a controlled temperature. The graphite stirrer was introduced into the crucible to make mixing process when the molten temperature reached 850 °C. The stirring was carried out for 45 minutes at the speed of 200 rpm. Silicon carbide particles were preheated to 200 °C and introduced into the vortex created in the molten alloy. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminum alloy melt. The simplest and best commercially used technique is known as vortex technique or stir-casting technique. The vortex technique involves the introduction of pre-treated mould and is allowed to cool in air. The prepared composites of size 200 x 80 x 20 mm as shown in figure. 1 (a) & (b).

Table 1. Mechanical properties of the reinforcement materials

Materials	**Density (g/cc)**	**Melting Point (°C)**	**Tensile Strength (MPa)**	**Poisson's Ratio**	**Young's Modulus (GPa)**
Aluminium	2.69	660	0.145– 0.186	0.3	0.145 – 0.186
SiC	3.21	2830	0.03448 - 0.1379	0.183 - 0.192	410.47

Table 2. Chemical Composition of the Aluminum Alloy 6063 (AA 6063)

Elements	**Weight (%)**	**Elements**	**Weight (%)**
Copper (Cu)	0.68	Titanium (Ti)	0.009
Silicon (Si)	11.12	Chromium Cr)	0.009
Manganese (Mn)	0.32	Lead (Pb)	0.005
Magnesium (Mg)	0.73	Tin (Sn)	0.005
Iron (Fe)	0.31	Nickel (Ni)	0.002
Zinc (Zn)	0.002	Lithium (Li)	0.027
Aluminum (Al)	86.781		

2.2 Wire Electrical Discharge Machining (WEDM)

The procedure in which material is removed by generating a series of discrete sparks between electrode and work piece immersed in a liquid dielectric medium. A thin electrically conductive brass wire is used as the electrode with the diameter of 0.25 mm. The electrode shows significant role in which affects the material removal rate and the tool wear rate. The selection of machining parameters in a machining process significantly affects production rate and quality of machined components.

The charmilles Wire-EDM was used to conduct the experiments based on the experimental run obtained from the design of experiments. AA6063/SiC has been used as the work piece material and a brass wire has been used as the wire electrode. Deionized water has been used as the dielectric medium in all these experiments. Each specimen has been machined to a dimension of 20 mm diameter.

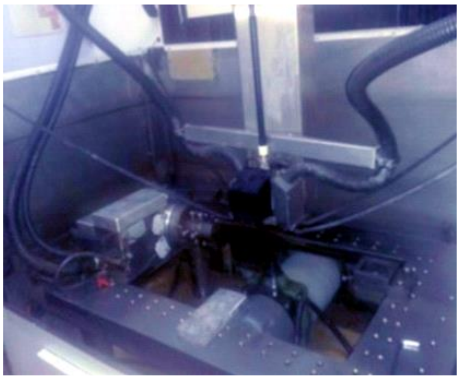

Figure 2. Manufacturing of composites on Wire EDM

2.3 Statistical Study

The examination was carried out by T-test and analysis of variance (ANNOVA) was performed in which process parameters were statistically significant (p = 0.05) and the regression analysis is the aspects employed to estimate the quality of measurement of surface of the hole. In the present study all the designs, plots and analysis have been carried out using Minitab 17 tool.

2.4 Scanning Electron Microscopy

Scanning electron microscope were observed in the surfaces of samples in LEO-1450VP, as well the chemical analyses on the surfaces were performed by using the EDAX (Energy Dispersive X-Ray Analysis) system of the equipment.

3. Results and Discussion

3.1 Structure of the Composites

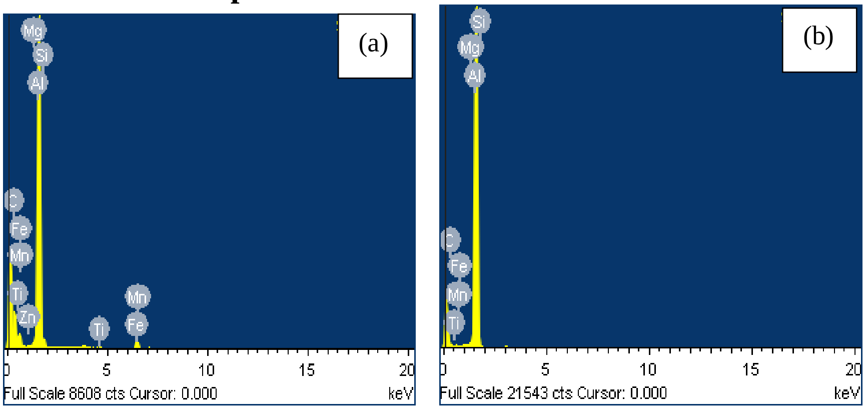

Figure 3 Energy dispersive X-ray spectrum (a). AA6063/SiC-B (b). AA6063/SiC-G

The elemental composition of the AA6063/SiC-B and AA6063/SiC-G composites is determined by Energy dispersive X-ray spectrum as shown in. Figure 3 (a) and 6 (b) The predominant elements such as Carbon, Silicon, Aluminum, Ferrous, Manganese, Magnesium, Zinc, Titanium (C, Si, Al, Fe, Mn, Mg, Zn, Ti) present in the AA6063/SiC-B and AA6063/SiC-G metal matrix hybrid composites. The elemental compositions of AA6063/SiC-B and AA6063/SiC-G metal matrix hybrid composites in weight percentage are given in Table 4. The EDS was clearly shows that carbon and Aluminium are the major constituents, and the small amount of Manganese, Zinc and Titanium are in the hybrid composites.

Table 3. Elemental composition of the composites.

Elements	AA6063/SiC-B (Weight in %)	AA6063/SiC-G (Weight in %)
Si	0.82	0.21
Fe	1.07	0.18
Mn	0.01	0.01
Mg	0.18	0.63
Zn	0.02	0.02
Ti,	0.06	0.06
C	23.52	30.94
Al	rest	rest

3.2 Influence of Processing Parameters on Machining of the Composites

The surface roughness and MRR in different parameters and experimental runs are listed given in table 3.Usually lower values of surface roughness higher value of MRR as the target values are desirable. Hence, the data sequences have the smaller the better characteristics for surface roughness and higher the better characteristics of MRR. The values of average surface roughness and MRR are set to be the reference sequence.

The performance measures MRR and SR are found for experimental trials of WEDM [26] and given in Table 4. The ANNOVA results are presented to the effect of different machining parameters pulse on time, wire feed, gap voltage. As the pulse-off time is reduced, more sparks will be created. It is attributed to higher and produces larger chips. When the greater peak current, the smaller is the machining time, as the machining rate is proportional to peak current. MRR increases as the supplied energy increases. It is directly depends on the number of sparks produced per second. Higher pulse on time requires the discharge energy induced for a longer time which results in large craters as shown in table 5.

Table 4. Different Constraints of the experimental values

Pulse on Time (µs)	Wire feed (m/min)	Gap Voltage (Volts)	(a) AA6063/SiC-B		(b) AA6063/SiC-G	
			Surface Roughness (µm)	MRR (g/min)	Surface Roughness (µm)	MRR (g/min)
75	80	100	3.788	0.00862	3.921	0.01033
75	90	80	3.895	0.00885	3.526	0.00778
75	100	90	3.557	0.01046	3.026	0.01072
85	80	90	3.408	0.01147	3.507	0.01097
85	90	100	3.592	0.00992	3.056	0.01121
85	100	80	2.979	0.01068	3.132	0.01483
95	80	100	3.215	0.01147	3.219	0.01264
95	90	80	3.295	0.01231	2.732	0.01325
95	100	90	3.108	0.01355	3.024	0.01069

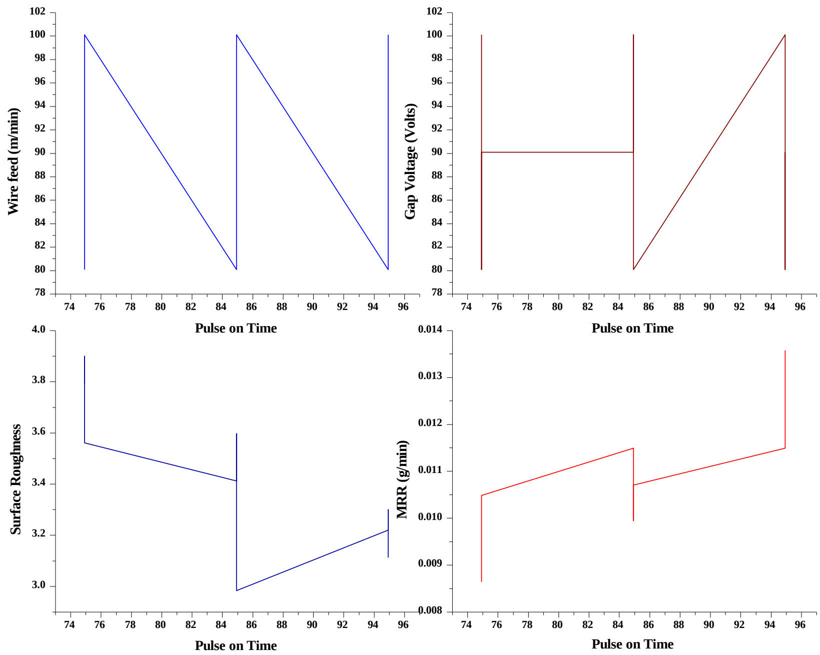

Figure 4. The different relations of the composite of AA6063/SiC-B

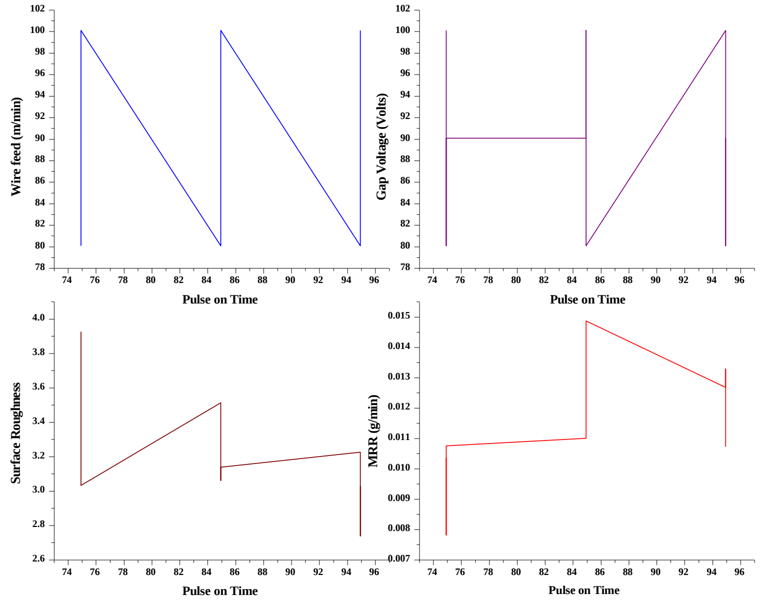

Figure 5. The various machining parameters of the composite of AA6063/SiC-G

Table 5. Analysis of Variance of AA6063/SiC-B and AA6063/SiC-G

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	116122	19353.6	601.52	0.000
Error	56	1802	32.2		
Total	62	117924			

Figs. 4 and 5 demonstrate the values of pulse on time in function of the variables of SR and MRR of AA6063/SiC - B and AA6063/SiC - G. It has been understood that by varying the SR and MRR values of the variables. It has been noticed that at higher peak current, near by the machined surface shows a higher SR due to uneven machined surface. On the other hand lower peak current produces little MRR and cause longer machining time. To attain more MRR, higher pulse on time, higher wire feed and medium gap voltage of AA6063/SiC - B is 0.01355. However, to attain more MRR, medium pulse on time and gap voltage and higher wire feed of AA6063/SiC - G is 0.01483. The comparable MRR of composites AA6063/SiC - B and AA6063/SiC - G has the SR is better for composite AA6063/SiC –B as indicated in the Figure 6.

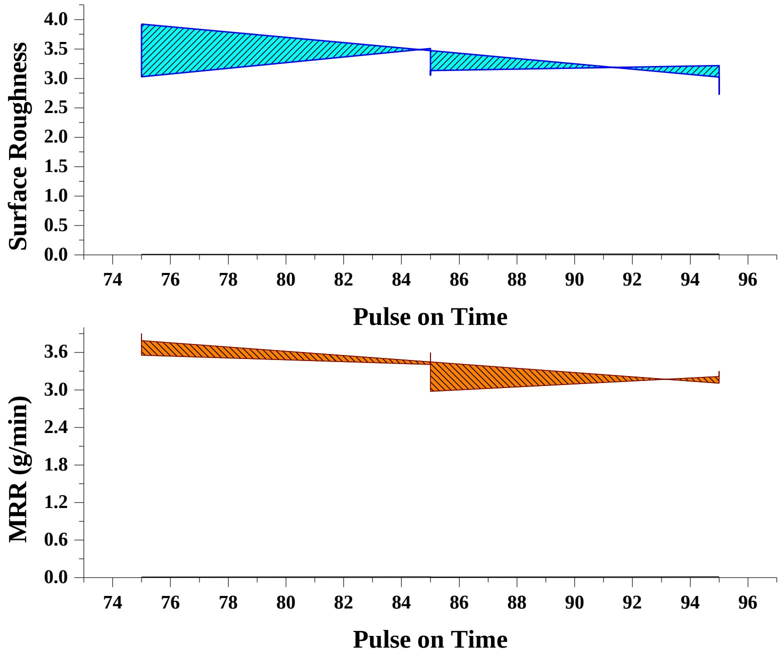

Figure 6. Comparison of Surface Roughness and MRR of AA6063/SiC-B and AA6063/SiC-G of composites

The quality of the surface produced due to deeper and wider craters produced by sparks. Increasing pulse on time from 75 to 85 μs generates higher discharge energy, which results into creation of more holes on the machined surface. Also, breakage of wire happened at higher discharge energy levels due to more temperatures. Drop of tensile strength at elevated temperature causes unstiffening of wire. The wire breakage was stopped by setting low wire tension and high flushing pressure to enhance cutting efficiency.

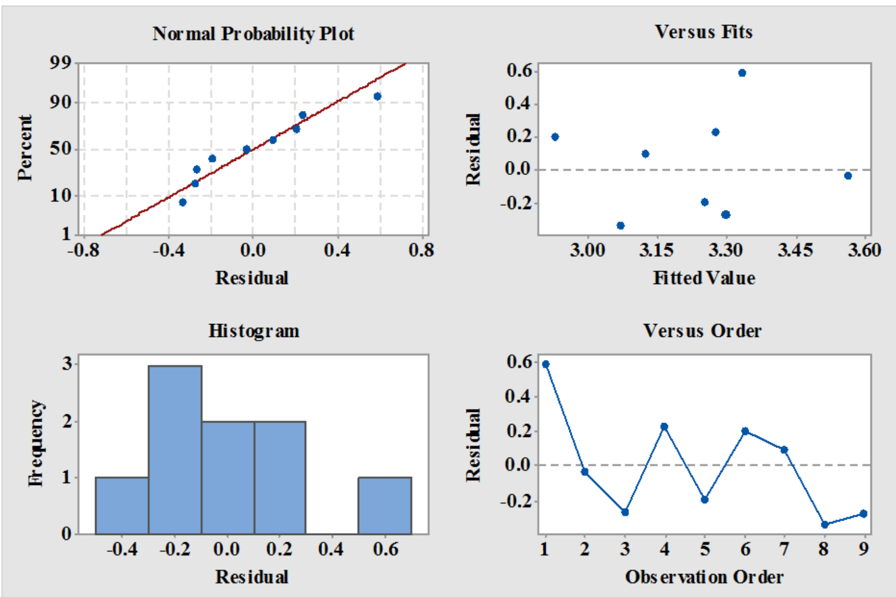

Figure 7. Residual plots of the various machining parameters on AA6063/SiC-G Composite

Fig. 7 shows that the residual follows an almost straight line in normal probability plot. Residuals possess constant variance as they are scattered randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to time or data collection order. The strongest interactions between various parameters can be observed from table. 6.

Table 6. The Mean and Standard Deviations of the machining factors

Factor	Mean	St.Dev
Pulse on Time (μs)	85.00	8.66
Wire feed (m/min)	90.00	8.66
Gap Voltage (Volts)	90.00	8.66
Surface Roughness (μm) G	3.238	0.356
MRR (g/min) G	0.011380	0.002005
Surface Roughness (μm) B	3.426	0.308
MRR (g/min) B	0.010814	0.001589

The confirmation test is an essential step for validating conclusions drawn from the experimental results. The optimum response characteristics at various levels of significant variables have been shown in figure 8.

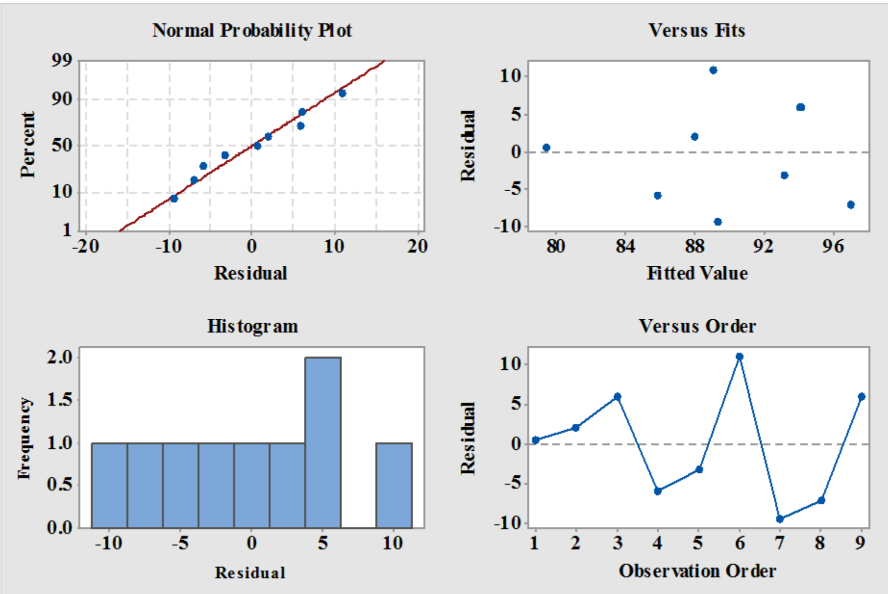

Figure 8. Residual plots of the various machining parameters on AA6063/SiC- G Composite

The analysis of experimental work is based on regression analysis for the establishing adequacy of the model. It computes F ratio for 95% level of confidence and parameters having 'p' value less than 0.05 are measured as significant. Since, the process of wire-EDM is non-linear in nature and the linear models fail to predict the response accurately therefore the linear model has been used. In order to improve accuracy of the model, the non-significant terms are eliminated by regressive the elimination process. Finally, the model was validated from the experimental runs and predication error was computed. The response parameters results are generated for the analysis of composite AA6063/SiC - B of figure 8, 9 and composite AA6063/SiC – G composite of figure 10 and 11 are shown below.

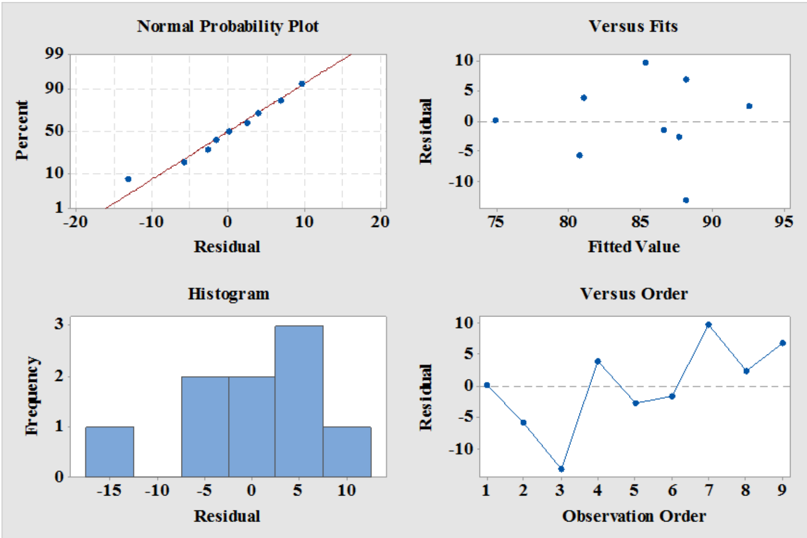

Figure 9. Residual plots of various Pulse on Time on AA6063/SiC-G Composite

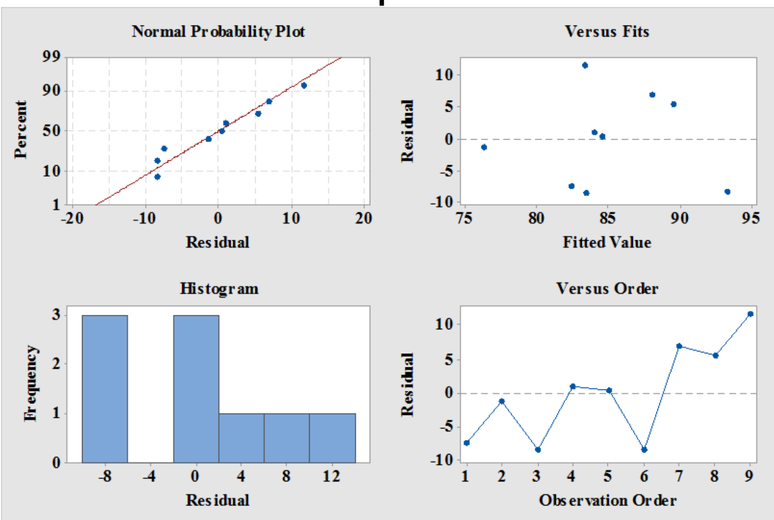

Figure 10. Residual plots of the various machining parameters on AA6063/SiC-B Composite

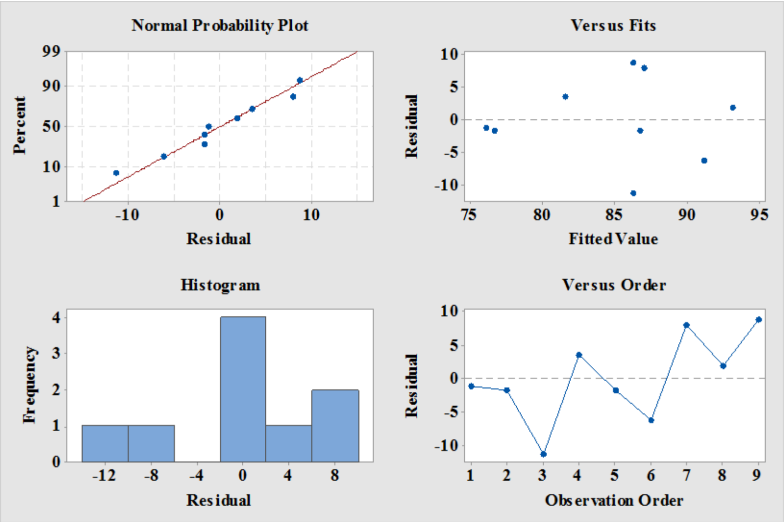

Figure 11. Residual plots of various Pulse on Time on AA6063/SiC – B Composite

Table 7. Regression Analysis of AA6063/SiC-B

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	2	272.28	136.14	2.49	0.163
Surface Roughness (µm) G	1	85.51	85.51	1.57	0.257
MRR (g/min) G	1	50.83	50.83	0.93	0.372
Error	6	327.72	54.62		
Total	8	600.00			

Using the regression analysis values of Table 7, the Figure 12 and 13 is plotted for identifying the optimum sequence of WEDM machine setting parameters for AA6063/SiC B and AA6063/SiC - G composites.

From the Figure 12, first level of gap voltage, third level of pulse on time, third level of pulse off time and third level of wire feed will results in both material removal rate (MRR), surface roughness (Ra), Using the regression values of Table 7, the Figure 12 is plotted for identifying the optimum sequence of WEDM machine setting parameters for AA6063/SiC - B composite.

From the Fig. 13, first level of gap voltage, third level of pulse on time, third level of pulse off time and third level of wire feed will results in both material removal rate (MRR), surface roughness (Ra). The main effects of the machine setting parameters on the regression values of composite AA6063/SiC - G are shown in Table 7 with their best parameter level of the regression equation is

Pulse on Time (µs) = 132.9 - 14.78 Surface Roughness (µm) G

Pulse on Time (µs) = 57.57 + 2410 MRR (g/min) G

Surface Roughness (µm) G = 4.258 - 89.61 MRR (g/min) G

Pulse on Time (µs) = 102.9-10.64 Surface Roughness (µm) G + 1456 MRR (g/min) G

Wire feed (m/min) = 152.8 - 16.67 Surface Roughness (µm) G - 779 MRR (g/min) G

Gap Voltage (Volts) = 59.0 + 8.7 Surface Roughness (µm) G + 255 MRR (g/min) G

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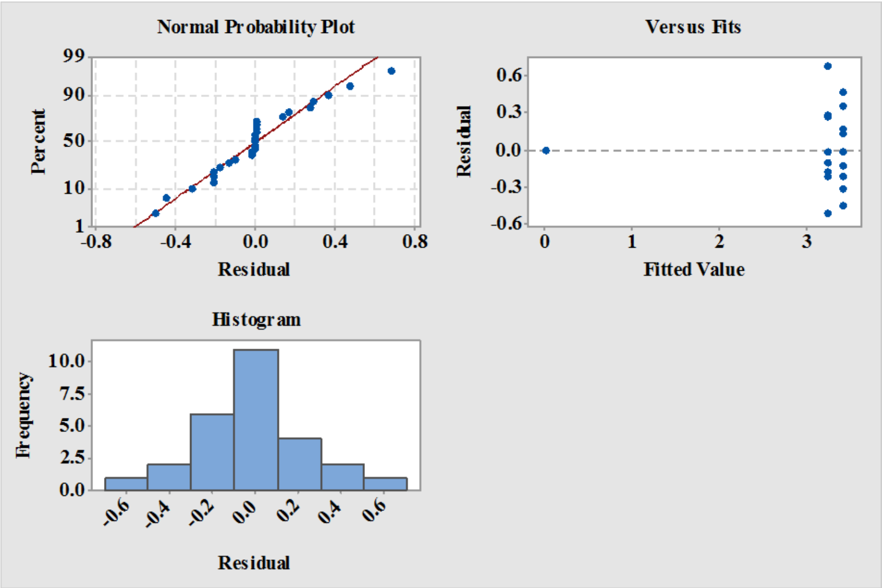

Figure 12. Residual plot of the various machining factors on AA6063/SiC-B and AA6063/SiC-G Composites

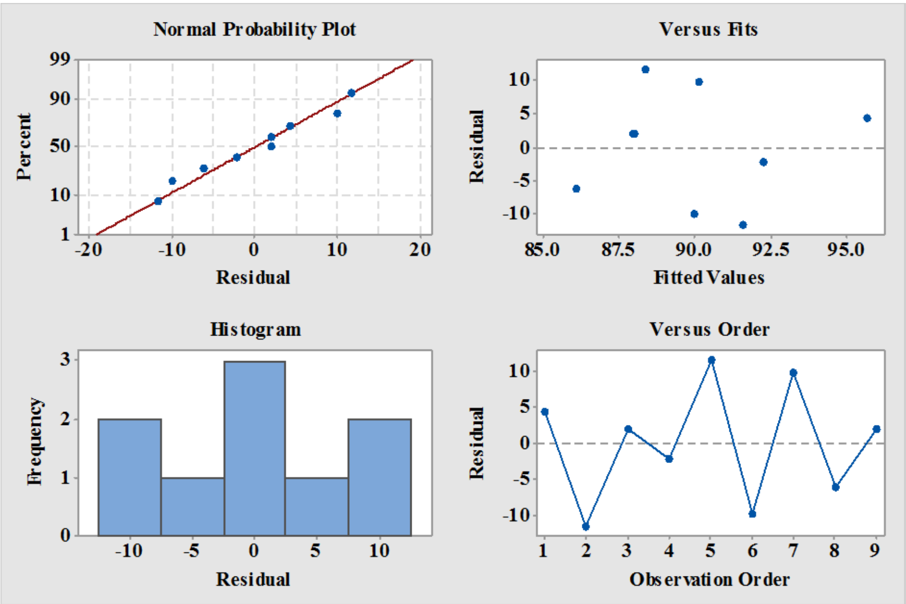

Figure 13. Regression fitted line plots of the various machining factors on AA6063/SiC-B and AA6063/SiC-G Composites

3.2 Surface Analysis

The worn out surface of AA6063/SiC-B and AA6063/SiC-G composites are shown in Fig. 14 and Fig. 15 respectively. It is revealed that generalized accumulation of AA6063 and SiC particles mixed with the oxides produced during the friction between the equivalent and the composite. While applied minimum load, a significant oxidation zones are not observed, since a moderate temperature is reached not enough to generate oxides of the alloy elements. Therefore, buildup of mixed oxide layers of monolithic AA6063/SiC alloy are present on the surface of the sample together with the Al particles, producing the way a low wear regime of weight losses,

In Fig. 14 and 15 it is observed the moderate presence of scratches crossing the surface with few particles of different sizes that may come from the oxides zones created during the wear process from the alloy specifically from the counterpart. The microanalysis on the worn out surface sample is observed the oxygen peak together with aluminum and silicon carbide peaks which obviously come from the sample material. It is important to observe that iron peak is present due to the abrasion of the particles against the steel surface, promoting a particles dispassion that posteriorly are embedded inner the oxides bulk produced from the worn out surface sample.

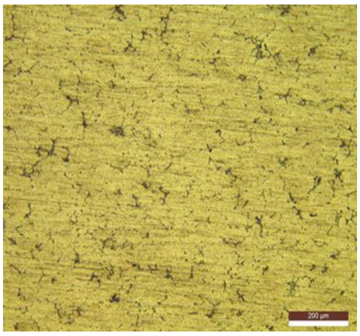

Figure 14. Microstructure of the wire EDM surface of composite AA6063/SiC-B

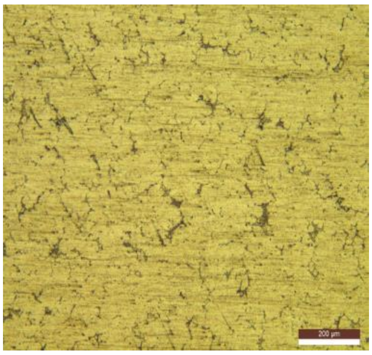

Figure 15. Microstructure of the wire EDM surface of composite AA6063/SiC-G

3.3 Microstructure of the Composites

It is observed that the main phase of aluminium which correspond to the alloy matrix of SiC with an approximately 10% in area fraction. The eutectic phase observed in the figure correspond to the aluminum rich eutectic phase and this phase it is precipitated around of the b-phase (secondary phase) which is composed of SiC. It is important to mention that eutectic phase and b-phase has precipitated together in the aluminium phase.

Figure 14 present the microstructure of the composite AA6063/SiC. It is observed both compounds, being the reinforcement of Al (grey zone) the particles distributed homogeneously over the metallic matrix, very few porosity zones are observed on the composite surface, this effect indicate that during the synthesis of the composite it take form homogeneously, in such way the AA6063/SiC alloy produce the wetting effect over the compacted aluminium particles. The synthesis of aluminum matrix composites improving the wetting effect with the addition of SiC reinforced with aluminium particles. In Fig. 15 is observed different AA6063 particles morphologies along the surface sample where predominantly exist the equiaxed particles with a bigger size and enlarged particles which may produce an improved cohesion of the composite. It has been demonstrated that the addition of reinforcement particles to the alloy matrix may improve the wettability of the composite by means of reducing the interface energy of the metal/ceramic, producing new products of interfacial reaction with the reinforcement particles. Thus, can be established that AA6063/SiC -B is an essential phase that may play an important role in strengthening crystal boundary and the consequent grain deformation.

4. Conclusion

In the paper represents the selection of optimum process parameters in WEDM process by considering the experimental results for maximizing the material removal rate and minimizing the surface roughness of the desired work piece.

The results endorse that pulse of time, wire feed and gap voltages are significant variables to analysis of variance and regression analysis.

The experimental conducted by the mathematical models using design of experiments of MRR, SR to determine the relation between machine variables and performance measures.

The optimum response characteristics such as MRR and SR are improved with 5% error by employing ANNOVA and Regression Analysis.

The best level of machine setting parameters gap voltage, pulse on-time and wire feed are identified for attaining maximum value of material removal rate and minimum values of surface roughness. The results showed that the optimal levels of machine setting parameters will help to attain the desirable values of performance measures.

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