EXPERIMENTAL INVESTIGATIONS ON WIRE EDM OF AL-SIC COMPOSITE USING TAGUCHI'S APPROACH

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Abstract: *The machinability study on Wire Electro Discharge Machining (WEDM) of Al6061/20%SiC has been investigated in the present exploration. The objective of this present investigation is to determine the best possible process parameter to obtain better machining performance during wire EDM of Al6061 matrix reinforced with 20 wt. % SiC which is fabricated through the stir casting processes. The machining parameters such as pulse on time, pulse off time (delay time) and servo voltage are deemed as input process variables. Rate of material removal and roughness of the machined surface were considered as performance measures under this investigation. Taguchi's design of experiment approach has been adopted for designing the experimental runs and L_9 orthogonal array has been selected for conducting the experiments. Analysis of Variance (ANOVA) is adopted for ascertaining the significance of process parameters. Taguchi's response analysis has been employed to determine the ascendancy of process parameters and the optimum process parameters were determined to obtain better machining performance.*

Keywords: *Al-SiC composites, WEDM, Taguchi's Approach, Orthogonal Array, ANOVA, Optimization*

1. INTRODUCTION

Aluminum alloys are the best choices for structural applications as it possess high specific strength, rigidity and modulus at elevated temperatures. However, the material properties need to be improved while going for the advanced structural applications. There are several research attempts were made for the improvement of the material properties among all the metal matrix composites (MMC) shows as most promising technique. The recent developments on MMC prove that incorporation of silicon carbide (SiC) particles enhances the metallurgical, tribological as well as mechanical properties like hardness, wear resistance and toughness. The machinability studies on MMC revealed that the proper choice of cutting tool plays a vital role. The surface roughness of the machined surface mainly depends on the cutting velocity and tool feed. The better surface quality on MMC is possible with higher cutting velocity and low rate of tool feed [1]. Manna and Bhattacharayya investigated the machinability of SiC particulate Al MMC during turning operation. The investigation proved that the built-up edges (BUEs) were formed while machining the material with high speed and lower depth of cut. Also their work proved that their machining tool was better than other tools like PCD [2, 3] and CBN [4]. In similar fashion, the influence of SiC reinforced ratios in MMC was examined and reported by few researchers. It was reported that the mechanical properties like toughness and hardness of the Al was improved with respect to increase in reinforcement ratio. However, the tensile property was greatly affected and resulted with different trend [5]. The possible application of WEDM method has identified as rapidly grown material removal process now-a-days because of the needs in various manufacturing applications and especially employed in fabricating tool and die applications, automobiles, nuclear and aerospace industries. The material removal takes place due to consecutive sparks occurred between the electrode wire and the work material in the presence of di-electric medium. The machining occurred irrespective of hardness of the material [6, 7].

Now-a-days Taguchi's approach is considered as an influential tool for increasing the rate of production by means of proper experimental planning and determining the better process parameters for single objective optimization which helps the manufacturer to produce parts with better quality and minimum cost [8]. Ashok Kumar Sahoo and Swastik Pradhan [9] presented a study on machining of aluminium metal matrix composites by Taguchi's approach. Mathematical models were evolved for determining roughness of the machined surface and flank wear. It is observed from the study that the developed mathematical models are found to be statistically significant for predicting the process parameters. Chiang and Chang [10] experimentally investigated the WEDM of Al_2O_3 reinforced composited with the help of Taguchi based approach and pulse on time has the great influence on the surface roughness and the material removal rate during the machining process. Various researchers employed Taguchi's method of planning the experiments and also single aspects optimization for Wire EDM of various work materials [11-14]. The dielectric medium chosen for the EDM plays an energetic role during the machining of Al/SiC MMC. The addition of tungsten power in the kerosene dielectric fluid significantly improved the material removal rate compared to kerosene dielectric fluid. It also helped to obtain a reduced recast layer thickness with improved surface finish [15, 16]. The power consumption during the machining process has to be addressed appropriate along with the tool life. Design of experiments (DOE) is one such tool used to accomplish the above objective. The DOE helps to obtain the desirability values for the machining process parameters through desirable functional analysis [17]. Optimization of machining process parameters greatly influences the final output responses. The techniques like grey relational theory (GRA) and analysis of variance (ANOVA) were used by many researchers in recent times for optimizing the Wire EDM machining of MMCs [18-19].

It is observed from the available literature that there is lack of literature on WEDM of Al6061/20%SiC Composite to analyze the process parameters. In this present investigation, an endeavor has been taken to establish the significance of machining parameters for the material removal rate and surface roughness during Wire EDM process. Taguchi's single objective optimization method is used to optimize the material removal rate and surface roughness in wire electrical discharge machining process.

2. MATERIALS AND METHODS

Taguchi's design of experiment approach is employed to plan the experiments. Total of three machining variables namely pulse on time, pulse off time, and servo voltage were selected as input process variables. The WEDM setup comprises of machining chamber, control panel, dielectric fluid circulation system as shown in Figure 1. Al 6061/20%SiC Composite is selected as the

Fig 1. Experimental Setup

work material and the composite is prepared by stir casting method. Aluminium silicon carbide composite is the key material in aerospace, automotive, marine applications and chemical industries because of their exceptional corrosion resistance. The work material is clamped in the vice provided inner side of the machining chamber. The input process parameters namely machining parameters namely pulse on time, pulse off time and servo voltage were varied. The experimental studies were performed on ELECTRONICA WEDM machine and the specifications are depicted in Table 1. Brass wire is used as electrode and connected between the rollers. The WEDM process parameters and their levels are shown in Table 2 and an L_9 orthogonal array has been selected for conducting the experiments. The de-ionized water has been chosen as dielectric fluid for conducting experiments and it is circulated between the tool and work piece. The machining was performed to make a through hole and MRR was measured using weight loss method. The roughness of the machined surface has been assessed with the help of Mitutoyo surface roughness tester (SJ-210).

Table 1: Machine Specification

Description	Details
Machine make	Electronica
Vertical axis movement (mm)	200
Horizontal axis movement (mm)	400
Wire material & Diameter (mm)	Copper wire & 0.25
Motor rating	3 phase, 430 V
Dielectric fluid	De mineralized water

Table 2: Parameters and Their Levels for WEDM of Al6061/20%SiC Composite

Factors	Process Parameters	Levels		
		1	2	3
A	Pulse On Time (µs)	105	108	111
B	Pulse Off Time (µs)	54	57	60
C	Servo Voltage (V)	20	25	30

3. RESULTS AND DISCUSSION

The experiments runs have been performed as per L_9 orthogonal array to examine the importance of input process variables on material removal rate and surface roughness. The opted orthogonal array and experimental observations were shown in Table 3. An effort has been taken to determine the best possible process variables for attaining the effective and competent machining process. In the WEDM process, higher material removal rate and lower surface roughness are the indicators of superior performance measure. So MRR is considered as larger the better criterion and roughness of the machined surface is considered as smaller the better criterion.

3.1 Determination of Optimum Process Parameter for Material Removal Rate

Figure. 2 illustrates the main effects plot for material removal rate during WEDM process. From the illustration, it is clear that the rate of material removal gets increased with an increase in pulse on time and it decreases with an increase in pulse off time. Also, pulse on time is the influential process parameter for material

Table 3: L_9 Orthogonal Array and Experimental Observations

S.NO	Pulse ON (µs)	Pulse OFF (µs)	Servo voltage (V)	MRR (mm^3/min)	S/N Ratio of MRR	Surface roughness (mm)	S/N Ratio of SR
1	1	1	1	6.9102	16.7899	2.68	-10.8066
2	1	2	2	8.0162	18.0794	2.33	-10.8814
3	1	3	3	6.5205	16.2856	2.02	-11.6640
4	2	1	2	13.00	22.2789	2.86	-11.9758
5	2	2	3	11.848	21.4729	2.69	-12.3400
6	2	3	1	11.048	20.8657	3.08	-14.1173
7	3	1	3	15.998	24.0813	3.07	-14.4855
8	3	2	1	10.4612	20.3916	2.61	-14.6960
9	3	3	2	10.8900	20.7406	2.48	-14.7597

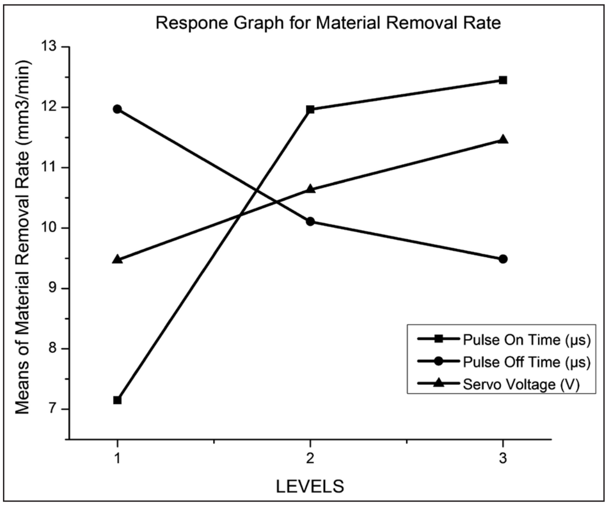

Fig 2. Response Graph for Material Removal Rate

Table 4: Taguchi Analysis - Response Table for MRR

Levels	Means			S/N Ratio		
	A	B	C	A	B	C
1	7.149	11.969	9.473	17.05	21.05	19.35
2	11.965	10.108	10.635	21.54	19.98	20.37
3	12.45	9.486	11.456	21.74	19.3	20.61
Delta	5.301	2.483	1.982	4.69	1.75	1.26
Rank	1	2	3	1	2	3
A – Pulse On Time (µs), B – Pulse Off Time (µs), C-Servo Voltage (V)						

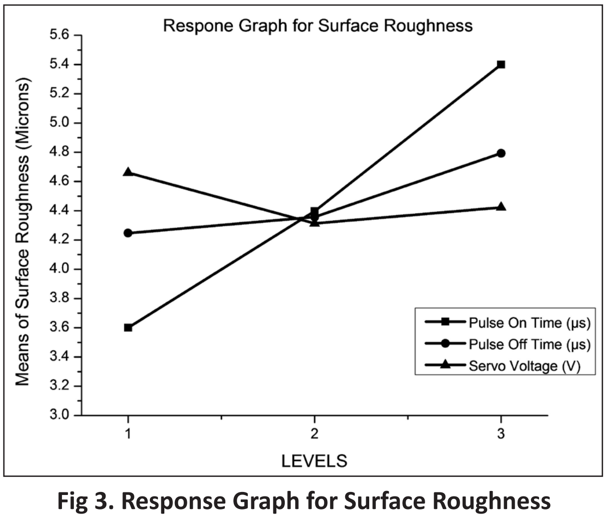

Fig 3. Response Graph for Surface Roughness

removal rate during Wire EDM process. With an increase in pulse on time, the discharge energy offered at the machining zone will be higher which results in powerful explosion, leading to increased material removal rate. Increasing the pulse-on time has the possibility of increasing the number of electrons striking on the work material surface, thus eroding the more amount of material from

Table 5: Taguchi Analysis - Response Table for Surface Roughness

Levels	Means			S/N Ratio		
	A	B	C	A	B	C
1	3.600	4.247	4.66	-11.12	-12.42	-13.21
2	4.397	4.357	4.313	-12.81	-12.64	-12.54
3	5.400	4.793	4.423	-14.65	-13.51	-12.83
Delta	1.8	0.547	0.347	3.53	1.09	0.67
Rank	1	2	3	1	2	3
A – Pulse On Time (µs), B – Pulse Off Time (µs), C-Servo Voltage (V)						

the surface of the work piece per discharge.

Taguchi's response analysis has been performed for material removal rate and the results are depicted in Table 4. In summary, the best possible machining variables to obtain higher material removal rate are $A_3B_1C_3$. This means the optimum level for material removal rate is: pulse on time at maximum level pulse off time at minimum level and servo voltage at maximum level. Pulse on time is the most contributing process variable and then it is followed by pulse off time and servo voltage.

3.2 Determination of Optimum Process Parameter for Surface Roughness

Figure. 3 shows the main effects plot for surface roughness during WEDM process. From the illustration, it is clear that the surface roughness increases with an increase in pulse on time and delay time. The superior discharge energy offered crater in larger manner which causes more roughness on the machine surface. Since there is an increase of pulse off time results in reducing the discharge energy in a greater manner leads to occurrence of minimum number of discharge for a specified duration of time causes better surface quality while comparing with increased pulse on time. Also, pulse on time is the influential process parameter for surface roughness during Wire EDM process.

Taguchi's response analysis has been performed for roughness of machined surface and the outcomes are depicted in Table 5. In summary, the best possible set of machining parameters for obtaining higher material removal rate are $A_1B_1C_2$. This means the optimum level for surface roughness is: pulse on time at minimum level, pulse off time at minimum level and servo voltage

Table 6: Analysis of Variance for WEDM of Al6061/20%SiC Composite

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Material Removal Rate (mm^3/min)						
Pulse On Time (μs)	2	0.005193	0.005193	0.002596	567.71	0.002
Pulse Off Time (μs)	2	0.001289	0.001289	0.000644	140.9	0.007
Servo Voltage (V)	2	0.000483	0.000483	0.000242	52.82	0.019
Error	2	9.1E-06	9.1E-06	4.6E-06	---	---
Total	8	0.006974	---	---	---	---
Surface Roughness (microns)						
Pulse On Time (μs)	2	2.17216	2.17216	1.08608	21.26	0.045
Pulse Off Time (μs)	2	0.62036	0.62036	0.31018	6.07	0.141
Servo Voltage (V)	2	0.08696	0.08696	0.04348	0.85	0.54
Error	2	0.10216	0.10216	0.05108	---	---
Total	8	2.98162	---	---	---	---

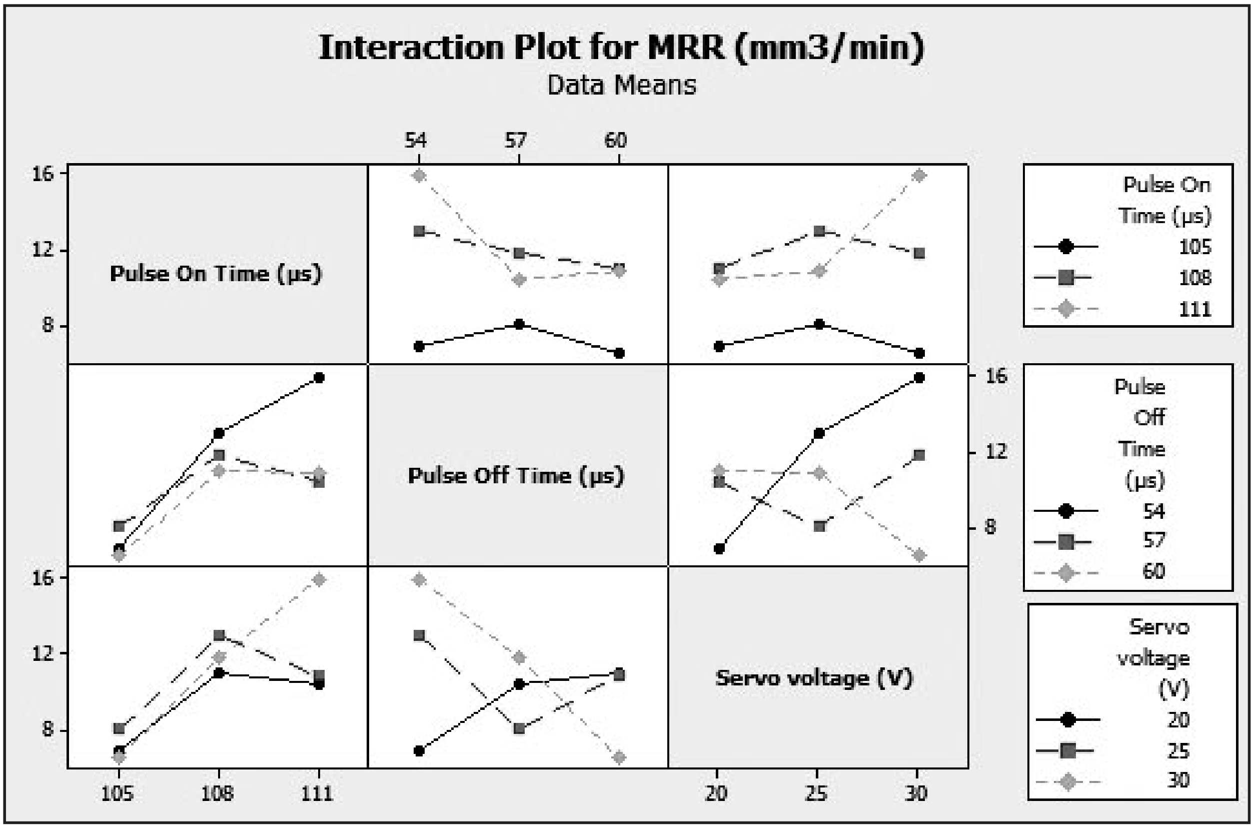

Fig 4. Interaction Graph for Material Removal Rate

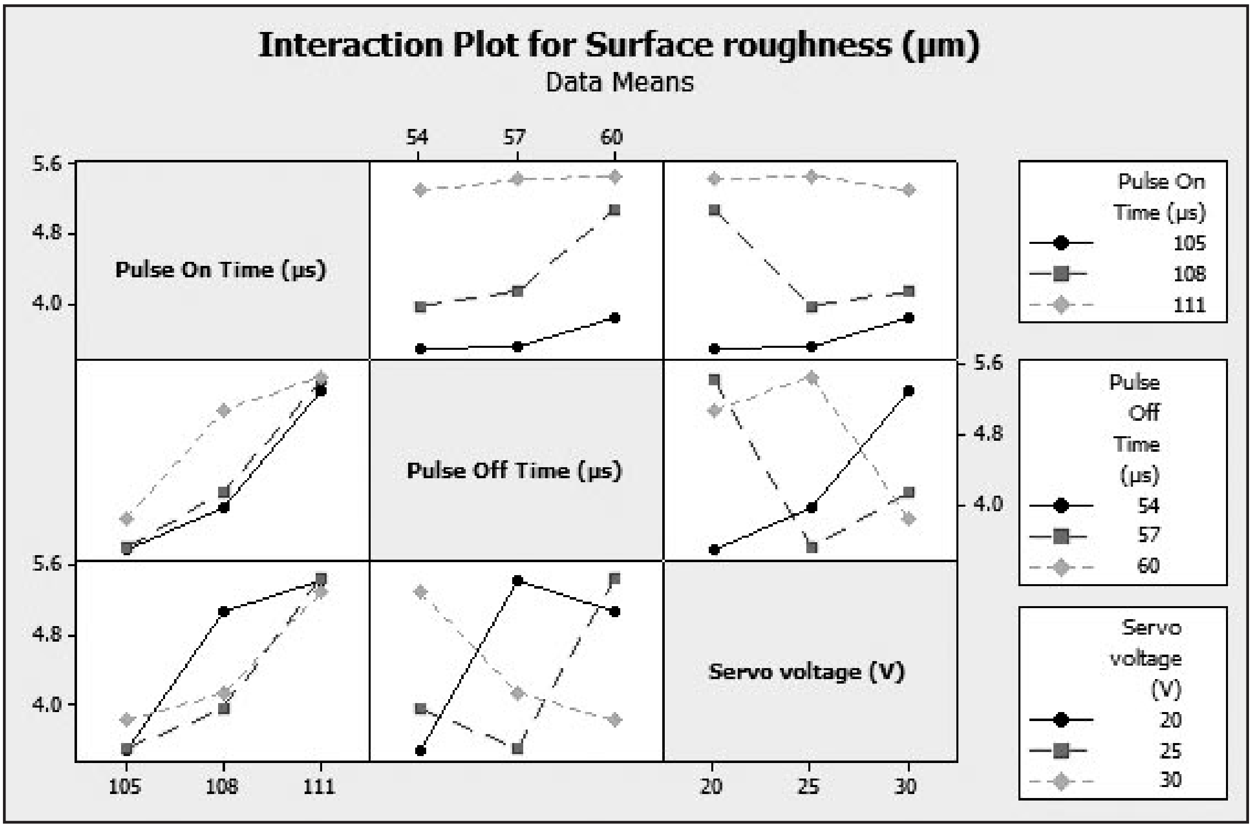

Fig 5. Interaction Graph for Surface Roughness

at intermediate level. Pulse on time is the most contributing parameter, followed by pulse off time and servo voltage.

3.3 Importance of Process Parameters on Performance Measures (ANOVA)

The significance of the process variables on desired performance measures are determined by Analysis of variance (ANOVA) statistically at 95% confidence level. The ANOVA results are shown in Table 6. It is witnessed from the investigation that the pulse on time is the predominant process parameter for material removal rate and surface roughness.

3.4 Interaction Analysis for WEDM of Al-SiC Composites

An interaction between two factors occurs when the difference in response between the levels of one factor is different at all levels from the other factor. The interaction of effect of various input variables on the desired performance measures are analyzed for WEDM of Al SiC composites and presented in this section.

3.5 Interaction effect for MRR in WEDM of Al-SiC Composites

The interaction plot for material removal rate is shown in Figure 4 and it is depicted from the interaction plot, that the combination of pulse off time and servo voltage has the significant interaction effect on material removal rate. At the same time the combination of pulse on time and pulse off time also have significance interaction with the material removal rate.

3.6 Interaction Effect for Surface Roughness in WEDM of Al-SiC Composites

The interaction plot for surface roughness is shown in Figure 5 and it is depicted from the interaction plot, that the combination of various input process variables have the significant interaction effect on surface roughness.

4. CONCLUSIONS

This present exploration details the single aspects optimization of WEDM of Al6061/20%SiC Composite using Taguchi’s Analysis. The rate of material removal and roughness of the machine surface are the performance measures considered in this exploration. Following conclusion were obtained from this experimental research:

- Taguchi's single response analysis determines the best possible process variable for attaining improved machining rate and surface quality. Taguchi's S/N ratio has been used to ascertain the best possible process parameters.
- The predominance of various considered input process parameters on the desired output machining aspects are revealed by main effect plots (Response Graphs). The pulse on time is the predominant machining variable for all the output machining characteristics.
- The suggested Taguchi's method is an opposite method to determine the best possible set of input process variables based on the selected output machining characteristics for obtaining better machining performance.
- From the ANOVA analysis it is depicted that the pulse on time is considered as the predominant machining variable for both desired performance characteristics material removal rate and surface roughness and also it is followed by pulse off time and servo voltage. It is corroborated from the Taguchi's response analysis have the close relationship with the results of ANOVA analysis.
- The present exploration helps the industries to improve production rate and quality of product in WEDM process.

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The topics on various aspects of manufacturing technology can be discussed in term of concepts, state of the art, research, standards, implementations, running experiments, applications, and industrial case studies.

Authors from both research and industry contributions are invited to submit complete unpublished papers, which are not under review in any other conference or journal.

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