Multi-Performance Optimization of Wire Cut EDM Process Parameters on Surface Roughness of AA7075 / B_4C_p Metal Matrix Composites

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***Abstract* —** This paper focus on multi performance optimization of process parameters for wire cut electric discharge machining of AA7075/B_4C (15%) metal matrix composites processed by stir casting technique using taguchi's design of experiment and regression analysis. The machining was performed as per design of experiments approach using L_9 orthogonal array. Four wire cut electric discharge machining parameters namely pulse-on-time (T_{ON}), pulse-off-time (T_{OFF}), spark voltage (SV) and wire tension (WT) were chosen as machining process parameters. Signal-to- noise ratio is used to find the optimal combination of process parameters. The mathematical relationships between wire cut electric discharge machining input process parameters and response parameter are established to determine optimal values of surface roughness by using regression analysis. The Analysis of variance (ANOVA) and F-test are performed to obtain statistically significant process parameters. The generated optimal process conditions have been verified by conducting confirmation experiments and predicted results have been found to be in good agreement with experimental findings.

Key Words: *AA-7075, B_4C_p, Metal Matrix Composites, Surface Roughness, Taguchi Method, Regression Analysis.*

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I. INTRODUCTION

Conventional monolithic materials fail to compete in the market because of their limitations. The properties like strength, stiffness, toughness and density are the barriers for wide usage of the materials under different working conditions. To overcome these limitations and to meet the requirements, composites are most widely used materials. Metal matrix composites (MMC) are a relatively new class of materials characterized by lighter weight, greater strength and wear resistance than those of conventional materials. Due to their superior strength and stiffness, MMCs have good potential for application in the automotive and aerospace industries. One of the factors that prevent most of the manufacturers from embracing MMC technology is the difficulty of machining these materials. The machining of MMC is very difficult due to the highly abrasive and intermittent nature of the reinforcements. MMC components are mostly produced using near net shape manufacturing methods and are subsequently finish machined to the final dimensions and surface finishes. Conventional tool materials such as high-speed steel and uncoated-carbides cannot be used for machining MMCs as the cutting tool undergoes very severe damage.

To overcome the tool damage caused in the conventional machining process, non conventional machining techniques are employed for effective machining of MMCs. Improved surface finish and low tool wear is observed as there is no contact between tool and work piece material. Wire cut EDM is slightly modified version of the conventional EDM process, which uses an electrode to initialize the sparking process. Wire cut EDM utilizes a continuously travelling wire electrode made of copper, brass, tungsten or molybdenum of diameter 0.04-0.40mm. The wire is kept in tension using a mechanical tensioning device which increases the precision of machining. The wire is passed through the work piece where sparking takes place. The spark temperature is so high that the material is removed by vaporization. There is a very small gap between wire and work piece hence no contact between the work piece and the wire which eliminates the mechanical stresses during machining. Wire cut EDM is the most widely used manufacturing process due to its capability of producing intricate shapes irrespective of hardness and toughness of material. This process is extensively used in mould and die making industries, aerospace industries, automotive industries etc. Many researchers have done work on machining of metal matrix composite materials by electrical discharge machining. By observing previous work material removal rate, surface roughness, effect of contents on machining and tool wear are determined by varying the parameters such as current, pulse on time, pulse off time, gap voltage, wire tension, type of dielectric medium, pressure of dielectric etc. By observing the previous work in the area of Wire cut EDM of metal matrix composites, there is a lot of scope for present work. In the present work, wire electric discharge machining of AA7075 alloy reinforced with B_4C_p particles have been studied. The effect of parameters like pulse-on-time, pulse-off-time, spark voltage and wire tension on mach inability characteristics of AA7075/ B_4C_p metal matrix composites is studied.

II. Materials and Methods

A. *Material*

The aluminium alloy 7075 based metal matrix composite, made by stir casting having 15% B_4C particles (by weight) as reinforcement were used as the work pieces. The work pieces were of rectangular shape having a thickness of 10 mm. Table.1and 2 shows the chemical compositions and mechanical properties of the matrix of the metal matrix composite used in this study.

Table1. Chemical Composition of AA- 7075

Elements	% .wt of Composition
Aluminium	87.1 - 91.4
Manganese	Max 0.3
Silicon	Max 0.4
Copper	1.2 – 2
Magnesium	2.1 - 2.9
Chromium	0.18 - 0.28
Zinc	5.1 - 6.1
Iron	Max 0.20

Table 2. Mechanical Properties of AA- 7075

Property	Values
Density (kg/cm^3)	2.81
Tensile strength (Mpa)	572
Yield Strength (Mpa)	503
Shear Strength (Mpa)	331
% of Elongation	11
Hardness BHN	150
Modulus of Elasticity (Gpa)	26.9
Melting point (^{o}C)	635

B. *Control Process Parameters*

In Wire cut EDM, a large number of factors are affecting the machining performance. Out of which only four process parameters are the primary factors contributing towards the heat input and subsequently have a significant influence on surface roughness. These four highly influencing parameters are: T_{ON} (pulse-on-time), and T_{OFF} (pulse-off-time), SV (spark voltage) and Wire Tension (WT). So in this work, these four factors are selected as design factors. After identifying the design factors, a large number of trial runs were conducted to find out the possible working ranges of these process parameters. Table 3 shows the control parameters and their levels consider for this experimentation.

Table 3. Control Parameters and Levels

S. No	Machining Parameters	Levels			Units
		1	2	3	
A	Pulse-ON-Time	110	120	130	µ sec
B	Pulse-OFF – Time	45	50	55	µ sec
C	Spark Voltage	10	15	20	Volts
D	Wire Tension	7	8	9	Kg-f

C. *Taguchi Methodology*

Taguchi method, developed by Dr. Genichi Taguchi, is a set of methodologies for optimization of a process or product. The application of this technique has become widespread in many US and European industries after the 1980s. This method involves three stages: system design, parameter design, and tolerance design. Out of these three stages, the second stage – the parameter design – is the most important stage as the first stage – system design – is an initial functional design and may be far from quality and cost. However, the third stage – tolerance design – is dependent of cost. Therefore, the parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. Originally, Fisher was developer of classical experimental design but it is difficult to use mainly due to two reasons, first complexity, second, it needs the large number of experiments if number of the process parameters increases. This task was simplified by Taguchi by introducing a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only and thus, it results in a lot of cost as well as time saving. In the Taguchi method, the experimental values are transformed into a signal-to-noise (S/N) ratio η. The term "signal" represents the desirable value (mean) for output characteristic and the term "noise" represents the undesirable value for the output characteristic. Usually there are three categories of the performance characteristic in the analysis of the S/N ratio, that is, the lower-the-better, nominal-the-better and the higher-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the performance characteristic, the larger S/N ratio corresponds to the better performance characteristic. Therefore, the optimal level of the process parameters is the level having highest S/N ratio. Furthermore, statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. The

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74 – 79

optimal combination of the process parameters can be predicted by S/N ratio and ANOVA analyses. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design.

In this study, the parameter design of Taguchi method is adopted to obtain optimal machining performance in Wire cut EDM process. The S/N ratios are expressed on a decibel scale. Factor levels that have maximum S/N ratio are considered as optimal. The aim of this study was to produce minimum surface roughness (Ra) in an Wire cut EDM machining operation. Smaller-the-better quality characteristic is used for surface roughness as smaller Ra values represent better or improved surface roughness. The formula used for calculating S/N ratio is given below.

Smaller- the- better: It is used where the smaller value is desired.

$$\text{S/N Ratio} = -10 \log \frac{1}{n} \sum_{i=1}^{n} yi^{2} \text{------------------(1)}$$

Where y = observed response values and
n = number of replications.

Table 4. Experimental Values for Surface Roughness

Ex. No.	T_{ON} (µs)	T_{OFF} (µs)	SV (v)	WT (kg-f)	Ra (µm)	S/N Ratios
1	110	45	10	7	6.50	-16.25
2	110	50	15	8	6.70	-1652
3	110	55	20	9	6.50	-16.25
4	120	45	15	9	7.90	-17.95
5	120	50	20	7	6.80	-16.65
6	120	55	10	8	6.09	-15.64
7	130	45	20	8	8.44	-18.52
8	130	50	10	9	7.74	-17.77
9	130	55	15	7	8.00	-18.06

III. Results and Discussion

A. *Signal-to-Noise Ratios*

The purpose of the experimentation is to identify the factors which have strong effects on the machining performance. Factor levels that have maximum S/N ratio are considered as optimal. The aim of this study was to produce minimum surface roughness (Ra) in a wire cut EDM machining operation. Smaller-the-better quality characteristic is used for surface roughness.

Table 5.Response Table for S/N Ratios

Level	A	B	C	D
1	-16.35	-17.58	-16.58	-16.99
2	-16.77	-16.98	-17.51	-16.91
3	-18.12	-16.67	-17.15	-17.33
Max-Min	**1.78**	**0.91**	**0.94**	**0.41**
Rank	**1**	**3**	**2**	**4**

Table 6. Response Table for Means

Level	A	B	C	D
1	6.567	7.613	6.777	7.100
2	6.930	7.080	7.533	7.077
3	8.060	6.863	7.247	7.380
Max-Min	**1.493**	**0.750**	**0.757**	**0.303**
Rank	**1**	**3**	**2**	**4**

From mean of S/N ratios (Table 5) for surface roughness, it is found that pulse-on-time has highest rank '1'. Therefore, it has most significant effect on surface roughness. As pulse-on-time increases the surface roughness increases significantly. The wire tension has least effect on surface roughness. The order of influencing parameters for surface roughness is: pulse-on-time, spark voltage, pulse-off-time and wire tension. From Table 5, the optimal combination of process parameters for minimum surface roughness is found to be: *A1B3C1D2*. The symbol A, B, C and D represents process parameters: pulse-on-time (T_{ON}), pulse-off-time (T_{OFF}), spark voltage (V) and wire tension (WT) respectively and numbers represents the levels. This means, to have minimum surface roughness, T_{ON} should be set on level 1, T_{OFF} on level 3, SV on level 1 and WT on level 2.

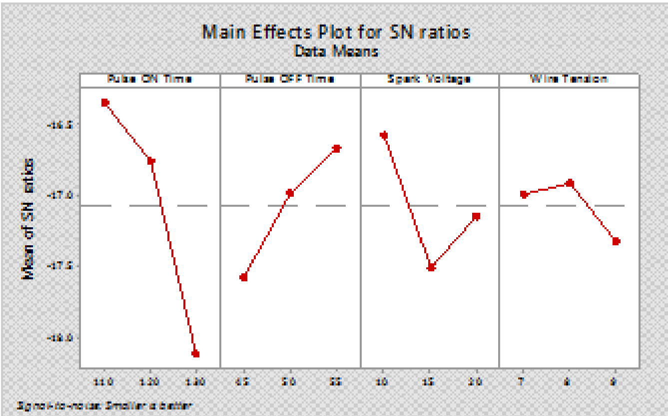

Fig.1.Main Effect Plot for S/N Ratios

ISSN: 2454-4248
74 – 79

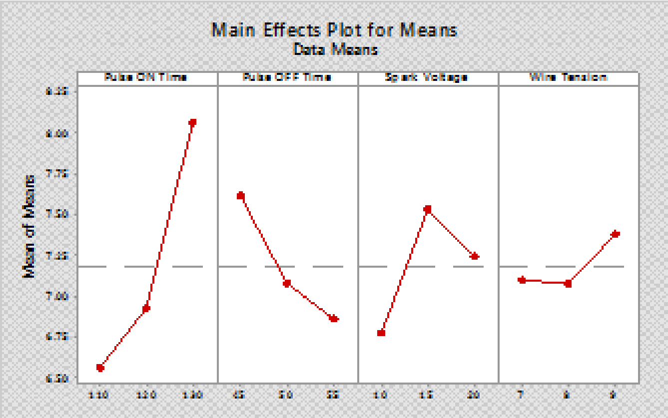

Fig.2.Main Effect Plot for Means

The mean S/N ratio graph for surface roughness is shown in Fig.1. It shows the main effect on surface roughness which is primarily due to pulse-on-time and spark voltage. The wire tension is found to be insignificant from the main effect plot. The greater is the S/N ratio, smaller is the variance of the surface roughness around the desired value.

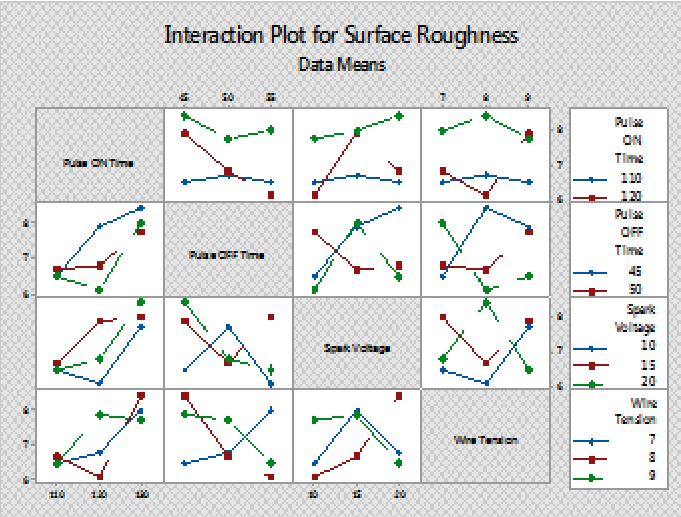

Fig.3.Interaction Plot for Surface Roughness

B. *Regression Analysis*

Utilizing the experimental data, mathematical model for surface roughness have been developed using multiple linear regression analysis. The dependent variable surface roughness can be conceived as a linear combination of the independent variables, namely pulse-on-time, pulse-off-time, spark voltage and wire tension. The data was analyzed by Minitab 17 software. Developed models can be used to predict values of surface roughness from any combinations within the range of variable studied. The following equations are the final regression models in terms of coded parameters for:

Surface Roughness (Ra):

Ra = 0.15 + 0.0747 Pulse on Time - 0.0750 Pulse off Time - 0.0470 Spark Voltage + 0.140 Wire Tension ------------- (2)

Table 7. Estimated Regression Coefficients

Term	Coeff	SE Coeff	T-Value	P-Value
Constant	0.15	3.53	0.04	0.968
A	0.0742	0.0198	3.77	0.020
B	-0.0750	0.0396	-1.89	0.131
C	0.0470	0.0396	1.19	0.301
D	0.140	0.198	0.71	0.519
S = 0.4851 R-Sq = 83.12% R-Sq(adj) = 66.25%				

The coefficients of model for surface roughness are shown in Table 7. The parameter R^2 describes the amount of variation observed in surface roughness is explained by the input factors. R^2 = 83.12 % indicate that the model is able to predict the response with high accuracy. Adjusted R^2 is a modified R^2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R^2 can be artificially high, but adjusted R^2 (66.25 %.) may get smaller. The standard deviation of errors in the modeling S= 0.4851.

Table 8. ANOVA Results for Surface Roughness

Source	DF	SS	MS	F	P
Regression	4	4.6378	1.1594	4.93	0.076
A	1	3.3451	3.3451	14.21	0.020
B	1	0.8438	0.8438	3.58	0.131
C	1	0.3313	0.3313	1.41	0.301
D	1	0.1176	0.1176	0.50	0.519
Error	4	0.9417	0.2354	-	-
Total	8	5.5794	-	-	-

ANOVA result for surface roughness is shown in Table 8.which clearly indicates that the pulse-on-time has greatest influence on surface roughness, followed by pulse-off-time having a P-value of 0.020 and 0.131. The wire tension was found to be insignificant with P-value of 0.519 respectively.The comparison of the predicted and experimental values of surface roughness as per the regression analysis is shown in Table 9 and Fig. 4.

Table 9. Experimental and Predicted values of Ra

Ex. No	Experimental Values of Ra(μm)	Predicted Values of Ra(μm)	% of Error
1	6.50	6.442	0.892
2	6.70	6.442	3.850
3	6.50	6.442	0.892
4	7.90	7.704	2.481
5	6.80	7.284	-7.117
6	6.09	6.579	-8.029
7	8.44	8.546	-1.255
8	7.74	7.841	-1.304
9	8.00	7.421	7.237

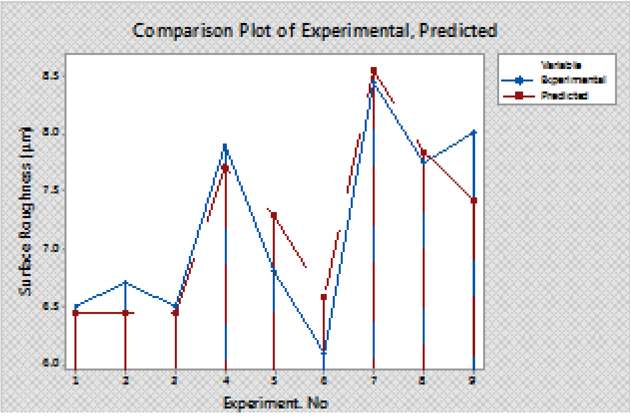

Fig.4. Predicted and Experimental Values of Ra

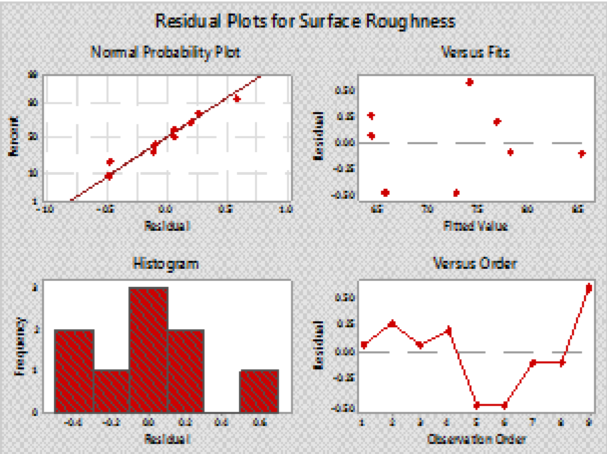

Fig.5.Residual Plot for Surface Roughness

The normal probability plot vs. residuals of linear model (Fig.5) shows that the residuals lie reasonably close to a straight line. This implies that the errors are distributed normally which gives support to the model to be significant. The experimental versus predicted values of surface roughness is shown in fig.4 and found to be very close to each other. Thus, the model developed using multiple linear regression analysis can be utilized to predict accurate prediction of the surface roughness in wire cut electric discharge machining of AA 7075/B_4C_p metal matrix composites. Fig.6 and 7 are shown in contour and optimization plots for surface roughness.

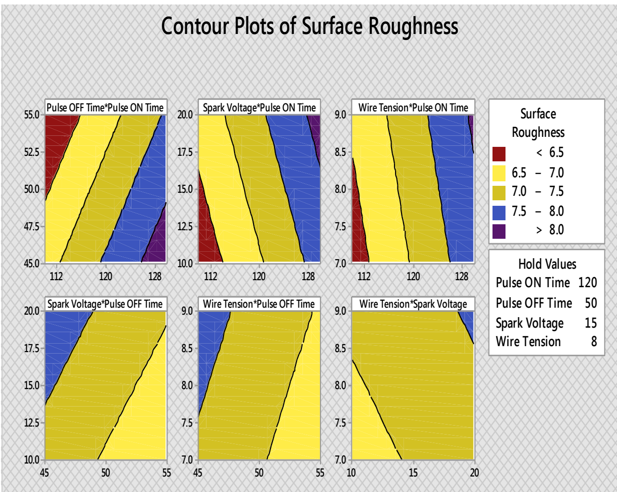

Fig.6.Contour Plot for Surface Roughness

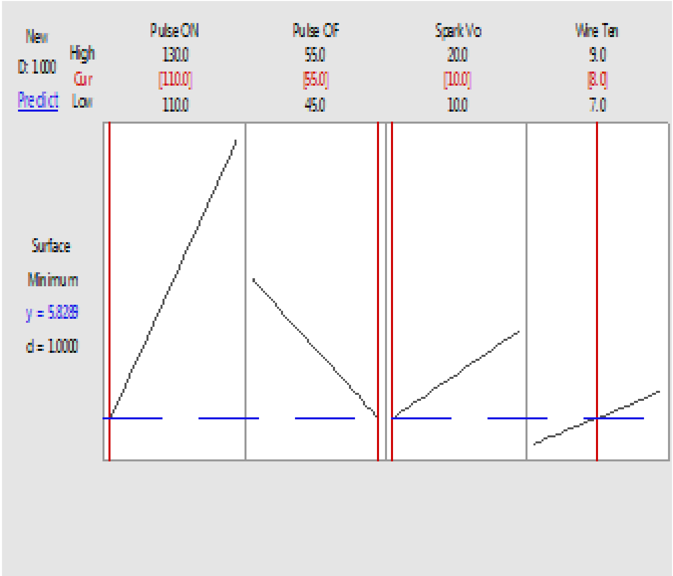

Fig.7.Optimization Plot for Surface Roughness

C. Confirmation Table

A Confirmation table was obtained to compare the Experimental results with the predicted results. The predicted results were obtained by the formula:

$$\gamma = \gamma_m + \sum_{i=1}^{o}(\gamma i - \gamma m) \text{------------------} (3)$$

Where, γ- is the optimal level of process parameter, γi - is the mean value of S/N ratio, γ_{m} - is the total mean S/N ratio and O is the number of main design parameter. The results of the confirmation test show a good agreement with the predicted result. The confirmation result is shown in Table 10. From the table, it can be easily seen that the experimental and the predicted values are very close to one another.

Table10.Confirmation Result for Multi Performance

Optimal Machining Parameters		
	Experimental	**Predicted**
Level	A1B3C1D2	A1B3C1D2
Ra (µm)	6.50	5.82

IV. Conclusions

This paper presented multi-performance optimization process parameters of wire cut EDM of AA 7075/B_4C_p metal matrix composites using taguchi's technique and regression analysis. From the S/N ratio (Table 4) the pulse-on-time was the most significant parameter contributing to the surface roughness, followed by spark voltage and wire tension was least significant parameter contributing to the surface roughness. So Increase in the pulse-on-time leads to the increase in the surface roughness. Mathematical models were developed using regression analysis for surface roughness to establish the relationship between machining variables and performance measures. Results predicted by the model are well matching with experiment results. The optimal machining performance of AA7075/B_4C_p metal matrix composites could be achieved at pulse-on-time of 110 µs, pulse-off-time of 55 µs, spark voltage of 10 volts and wire tension of 8 kg-f. This parameter combination in minimum surface roughness of 6.5 µm.

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