Modeling and Optimization of Wire EDM Process

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Abstract-- The present work is aimed to optimize the parameters of wire electric discharge machining (WEDM) process by considering the effect of input parameters viz. Time On, Time Off, Wire Speed & Wire Feed. Experiments have been conducted with these parameters in three different levels data related to process responses viz. Metal removal rate, surface roughness (Ra) have been measured for each of the experimental run. These data have been utilized to fit a quadratic mathematical model (RSM) for each of the responses, which can be represented as a function of the process parameters. Predicted data have been utilized for identification of the parametric influence in the form of graphical representation for showing influence of the parameters on selected responses. Predicted data given by the models (as per Taguchi's L_9 OA) design have been used in search of an optimal parametric combination to achieve desired yield of the process. Taguchi techniques has been used for optimization. The optimal value has been verified to the predicted value.

Index Term-- **Wire EDM, MRR, SR, RSM, Mg- Sic_P (magnesium silicon carbide)**

1. INTRODUCTION

WEDM process involves the complex erosion effect by rapid repetitive and discrete spark discharges between the wire tool electrode and work piece immersed in a liquid dielectric medium.[1] WEDM is used in the area of production of aerospace parts micro gas turbine blades and electronic components.[2]

As research work even in WEDM much standard references are not available for the selection of the parameters and the level for optimizing the performance characteristics.[3] Hence it is necessary to conduct an extensive experimental investigation to study the effect of different process parameters for the accuracy and surface finish of WEDM machined components an attempt is also made to obtain machinery performance with the RSM [4]

The highlights of this paper is to significance the process parameters and different machining condition on MRR and surface roughness of the Mg-sic mathematical models[6] are developed to correlate the process parameters and performance measures.[7,8]

2. EXPERIMENTAL WORK

Experiments are conducted in series with three levels, experimentation is developed using DOE with input parameters shown in table I.

Table I

SYMBOL	CONTROL FACTOR	UNIT	LEVEL 1	LEVEL 2	LEVEL 3
A	SPEED	rpm	500	1000	1500
B	FEED	mm/min	1.0	1.1	1.2
C	PULSE-ONTIME	µs	120	124	128
D	PULSE-OFFTIME	µs	42	44	46

INPUT PARAMETERS

Holes of 5mm diameter are drilled on 10mm thick Mg-sic plate. WEDM using molybdenum wire of diameter 0.18mm. The influence of process parameters on the machining of drilled hole is also analyzed. The average surface roughness (Ra) value of drilled hole is determined using surface roughness tester. The material removal rate (MRR) is evaluated as the average volume of material removed over the machining time in mm3/min. The experiments were performed on SPRINT CUT 734 DI WATER CUT WEDM is shown in fig.1. The experimental setup is shown in figure 2.The machined work piece is shown in fig.3. The molybdenum wire as tool electrode with flushed type dielectric fluid pressure 0.2 kgf/cm2 (distilled water) bath between work piece and electrode. Electrical power and controlling system is controlled with servo controlled resistance capacitance (Rc) circuit which ensures low discharge current with high frequency to control input process parameters.The analysis is done to study the main effects and their interactions to explore the effect of the influence of parameters on the performances. In this study, Taguchi method, a powerful tool for parameter design of the performance characteristics has been used to determine optimal machining parameters for maximization of MRR and minimization of SF in wire EDM.

Experiments have been carried out using Taguchi's L9 Orthogonal Array (OA) experimental design which consists of 9 combinations of four process parameters. According to the design catalogue (Peace, 1993) prepared by Taguchi, L9 Orthogonal Array design of experiment has been found suitable in the present work. It considers four process parameters (without interaction) to be varied in three discrete levels. Based on Taguchi's L9 Orthogonal Array design, the predicted data provided by the mathematical models can be transformed into a signal-to-noise (S/N) ratio; based on three criteria. The characteristic that higher value represents better machining performance, such as MRR, 'higher-the-better, HB; and inversely, the characteristic that lower value represents better machining performance, such as surface roughness is called 'lower-the-better', LB. Therefore, HB for the MRR, LB for the SF have been selected for obtaining optimum machining performance characteristics

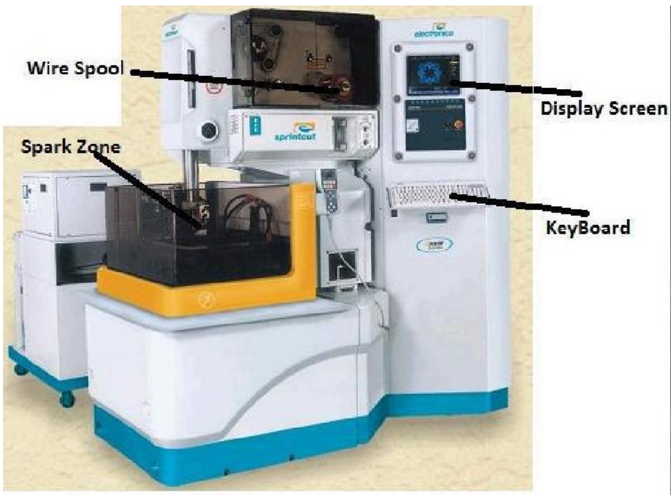

FIG. 1. SPRINT CUT 734 DI FIG. 2. MACHINING SETUP

WATER CUT WEDM

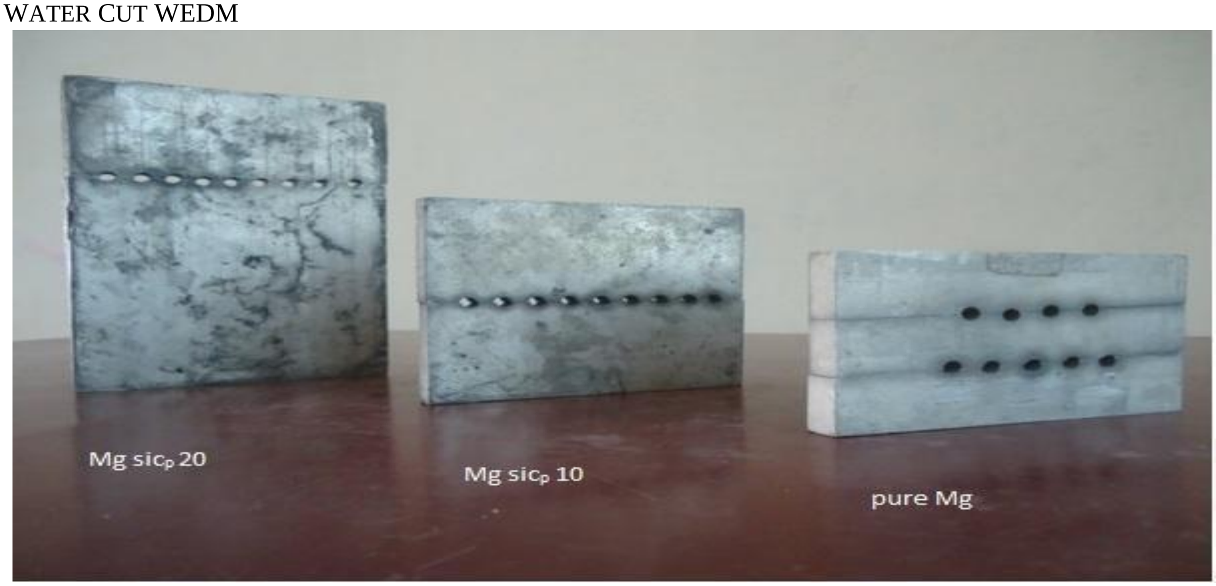

FIG. 3 .WEDM MACHINED WORKPIECES

L9 Orthogonal array

The nine cutting experiments with the assigned levels of the process parameters are run on selected L9 orthogonal layout. For both the work pieces are machined on the WEDM.

Table II
orthogonal array

S.No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Output responses

In this study most important output performances in WEDM such as material removal rate (MRR), surface roughness (RA) were considered for optimizing machining parameters. The surface finish value (in µm) was obtained by measuring the mean absolute deviation, Ra (surface roughness) from the average surface level using a computer controlled surface roughness tester.

The material removal rate (MRR) is calculated as,

$$MRR = \frac{(Wi - Wf)}{\rho * t}$$

Where, Wi = initial weight of workpiece (gm)
Wf = final weight of workpiece (gm)
t = machining time (sec)
ρ = density of magnesium (gm/mm3) = (7.8 * 10-3 gm/mm3)

Table III
Orthogonal Array And Experimental Results Of Mg Sic_P 10%

EXP.NO	CONTROL FACTORS				RESPONSES	
	A	B	C	D	MRR(mm³/sec)	RA(µm)
1	1	1	1	1	6.33	4.1295
2	1	2	2	2	6.48	3.769
3	1	3	3	3	6.58	3.7145
4	2	1	2	3	6.81	3.6605
5	2	2	3	1	6.73	3.607
6	2	3	1	2	6.99	3.7475
7	3	1	3	2	7.28	3.9875
8	3	2	1	3	7.14	4.026
9	3	3	2	1	7.13	4.161

Table IV
Orthogonal array and experimental results of Mg SiC_P 20%

EXP.NO	CONTROL FACTORS				RESPONSES	
	A	B	C	D	MRR(mm^3/sec)	RA(μm)
1	1	1	1	1	6.33	3.562
2	1	2	2	2	6.56	3.711
3	1	3	3	3	6.23	3.765
4	2	1	2	3	6.76	3.888
5	2	2	3	1	6.58	4.081
6	2	3	1	2	6.88	3.928
7	3	1	3	2	6.93	3.698
8	3	2	1	3	7.14	3.832
9	3	3	2	1	7.03	3.758

3. Optimization Steps Using Grey-Taguchi Method

3.1 To find S/N ratios values

In this step, the original response values are transformed into S/N ratio values. Further analysis is carried out based on these S/N ratio values. The material removal rate is a higher-the-better performance characteristic, since the maximization of the quality characteristic of interest is sought and can be expressed as

$$S/N = -10\log_{10}\left(\frac{\sum y^2}{n}\right).$$

Where n = number of replications and yij = observed response value

Where i=1, 2... ....n; j = 1, 2...k. The surface roughness and kerf width are the lower-the-better performance characteristic and the loss function for the same can be expressed as

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{y^2}\right).$$

The S/N ratio values for the experimental results were calculated and presented in the Tables below

Table V
S/N Ratio Values Of Mg Sic_P 10%

EXP.NO	CONTROL FACTORS				S/N RATIO	
	A	B	C	D	MRR(mm³/sec)	RA(µm)
1	1	1	1	1	16.0281	-12.3190
2	1	2	2	2	16.2315	-11.5245
3	1	3	3	3	16.3645	-11.3992
4	2	1	2	3	16.6429	-11.2720
5	2	2	3	1	16.5603	-11.1429
6	2	3	1	2	16.8895	-11.4760
7	3	1	3	2	17.2426	-12.0151
8	3	2	1	3	17.0740	-12.0975
9	3	3	2	1	17.0618	-12.3840

Table VI
S/N ratio values of Mg Sic_P 20%

EXP.NO	CONTROL FACTORS				S/N RATIO	
	A	B	C	D	MRR(mm³/sec)	RA(µm)
1	1	1	1	1	16.0281	-11.0339
2	1	2	2	2	16.3381	-11.3898
3	1	3	3	3	15.8898	-11.5153
4	2	1	2	3	16.5989	-11.7945
5	2	2	3	1	16.3645	-12.2153
6	2	3	1	2	16.7518	-11.8834
7	3	1	3	2	16.8147	-11.3593
8	3	2	1	3	17.0740	-11.6655
9	3	3	2	1	16.9391	-11.4991

3.2 To find normalized S/N ratio values

In the grey relational analysis, a data pre-processing is first performed in order to normalize the raw data for analysis. Normalization is a transformation performed on a single data input to distribute the data evenly and scale it into an acceptable range for further analysis. In this study, a linear normalization of the S/N ratio is performed in the range between zero and unity, which is also called the grey relational generating. yij is normalized as Zij (0≤Zij≤1) by the following formula to avoid the effect of adopting different units and to reduce the variability. The normalized material removal rate corresponding to the larger-the-better criterion can be expressed as

$$Zij = \frac{Yij+\min(Yij\ ,i=1,2,......n)}{\max(Yij\ ,i=1,2,3...n)-\min(Yij\ ,i=1,2,3..n)}$$

The surface roughness and kerf width should follow the lower-the-better criterion and can be expressed as

$$Zij = \frac{\max(Yij\ ,i=1,2,......n)-Yij}{\max(Yij\ ,i=1,2,3...n)-\min(Yij\ ,i=1,2,3..n)}$$

The normalized S/N ratio values are given in Tables below

Table VII
Normalised S/N values of Mg Sic_P 10%

EXP.NO	CONTROL FACTORS				NORMALISED S/N RATIO	
	A	B	C	D	MRR(mm³/sec)	RA(µm)
1	1	1	1	1	0	0.947
2	1	2	2	2	0.167	0.307
3	1	3	3	3	0.276	0.206
4	2	1	2	3	0.506	0.104
5	2	2	3	1	0.393	0
6	2	3	1	2	0.701	0.268
7	3	1	3	2	1	0.702
8	3	2	1	3	0.861	0.769
9	3	3	2	1	0.851	1

Table VIII
Normalised S/N values of Mg Sic_P 20%

EXP.NO	CONTROL FACTORS				NORMALISED S/N RATIO	
	A	B	C	D	MRR(mm³/sec)	RA(µm)
1	1	1	1	1	0.116	0
2	1	2	2	2	0.378	0.301
3	1	3	3	3	0	0.407
4	2	1	2	3	0.598	0.643
5	2	2	3	1	0.400	1
6	2	3	1	2	0.727	0.791
7	3	1	3	2	0.781	0.275
8	3	2	1	3	1	0.537
9	3	3	2	1	0.886	0.393

3.3 To find grey relational coefficient

The grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized experimental results. The grey relational coefficient can be expressed as

$$(Yo(k), Yi(k)) = \frac{\Delta \min + \mathcal{E}\Delta max}{\Delta oj(k) + \mathcal{E}\Delta \max}$$

Where j = 1, 2...n; k = 1, 2...m, n is the number of experimental data items and m is the number of responses. yo (k) is the reference sequence (yo(k) = 1,k=1,2...m); yj(k) is the specific comparison sequence.

Δoj = || yo(k) - yi(k) || = the absolute value of the difference between yo(k) and yj (k).

Δ Min = min min || yo(k) - yi(k) || is the smallest value of yj(k).

Δ Max = max max || yo(k) - yi(k) || is the largest value of yj(k).

Where ξ is the distinguishing coefficient, which is defined in the range 0≤ ξ ≤1. The WEDM process parameters are equally weighted in this study, and therefore ζ is 0.5

3.4 To find grey relational grade

The grey relational grade is determined by averaging the grey relational coefficient corresponding to each performance characteristic. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation with the objective function of an overall grey relational grade. Table shows the grey relation coefficient and grey relational grade for each experiment using the L9 orthogonal array. The higher grey relational grade reveals that the corresponding experimental result is closer to the ideally normalized value.

Table IX
Grey relational co-efficient and grey relational grade of Mg Sic_P 10%

Exp.no	Control factors				Grey relational co-efficient		Grey grade
	A	B	C	D	MRR(mm³/sec)	RA(μm)	NO UNIT
1	1	1	1	1	1	0.053	0.6185
2	1	2	2	2	0.833	0.693	0.397
3	1	3	3	3	0.724	0.794	0.395
4	2	1	2	3	0.494	0.896	0.430
5	2	2	3	1	0.607	1	0.392
6	2	3	1	2	0.291	0.732	0.518
7	3	1	3	2	0	0.298	0.813
8	3	2	1	3	0.139	0.231	0.7325
9	3	3	2	1	0.149	0	0.885

Table X
Grey relational co-efficient and grey relational grade of Mg Sic$_P$ 20%

EXP.NO	CONTROL FACTORS				Grey relational coefficient		GREY GRADE
	A	B	C	D	MRR(mm³/sec)	RA(µm)	NO UNIT
1	1	1	1	1	0.884	1	0.347
2	1	2	2	2	0.622	0.699	0.431
3	1	3	3	3	1	0.593	0.395
4	2	1	2	3	0.402	0.357	0.568
5	2	2	3	1	0.6	0	0.727
6	2	3	1	2	0.273	0.281	0.643
7	3	1	3	2	0.219	0.725	0.551
8	3	2	1	3	0	0.463	0.759
9	3	3	2	1	0.114	0.607	0.6850

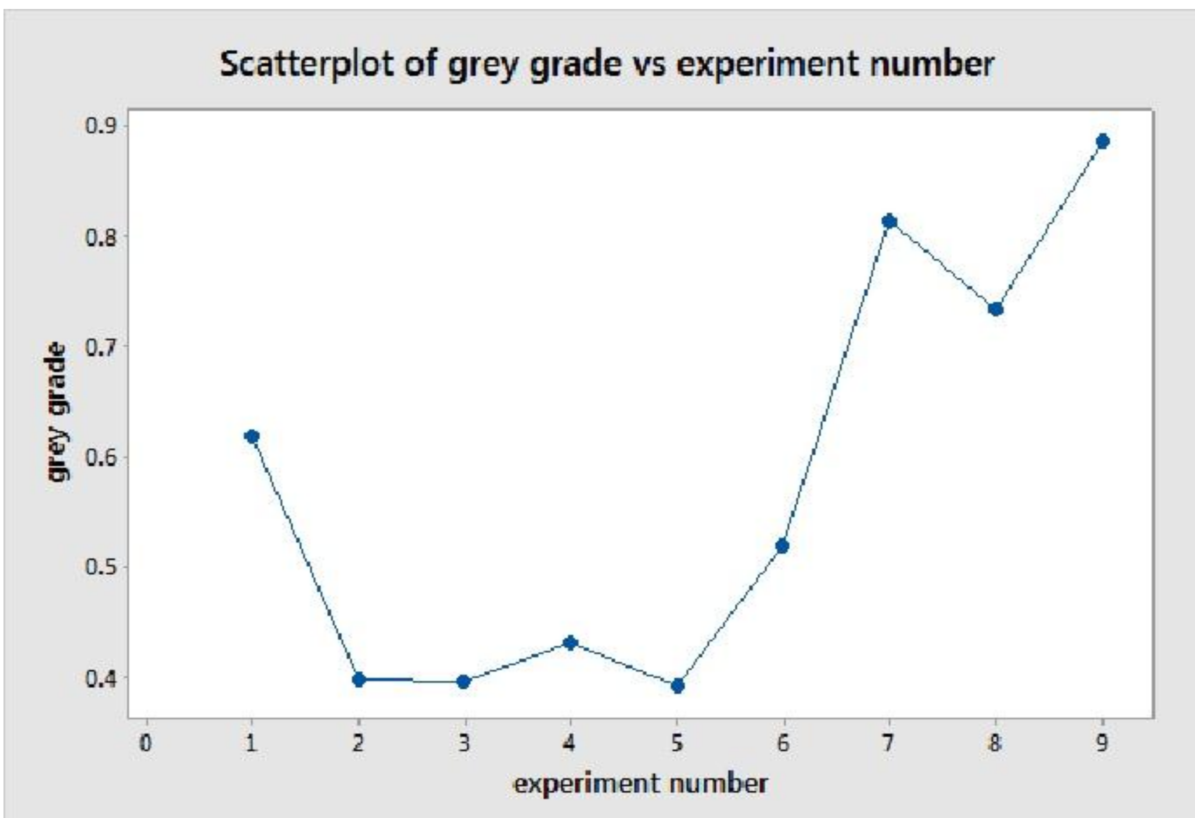

Fig. 4 . Graph for grey relational grades for maximum MRR , minimum Ra for Mg Sic$_P$ 10%

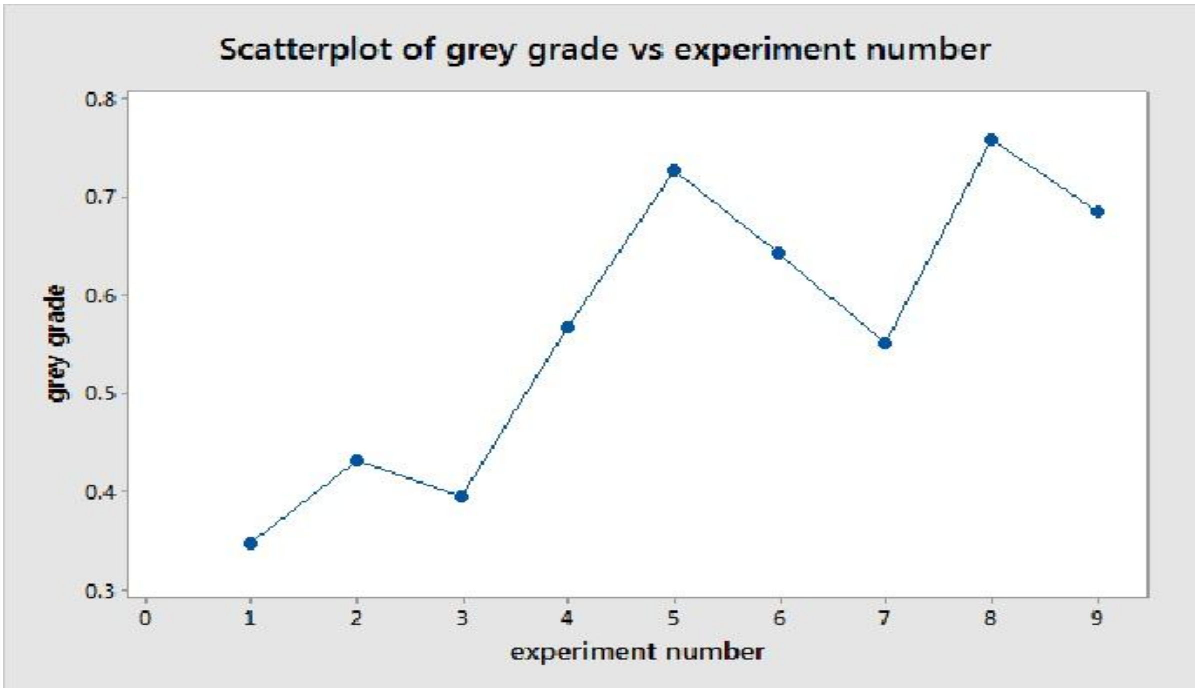

Fig. 5 . Graph for grey relational grades for maximum MRR , minimum Ra for pure Mg Sic_P 20%

3.5 To find optimum levels of the factors

Since the experimental design is orthogonal, it is possible to separate out the effect of each machining parameter on the grey relational grade at different levels as the mean of the grey relational grade for the gap voltage at levels 1, 2 and 3 can be calculated by averaging the grey relational grade for the experiments 1 to 3, 4 to 6, and 7 to 9, respectively. The mean of the grey relational grade for each level of the other machining parameters can be computed in a similar manner. The mean of the grey relational grade for each level of the machining parameters is summarized and shown in Tables

Table XI
The main effects of the factors on the grey relational grade for Mg Sic_P 10%

SYMBOL	**CONTROL FACTORS**	**LEVEL 1**	**LEVEL 2**	**LEVEL 3**
A	**SPEED**	**0.4702**	**0.447**	**0.8102 ***
B	**FEED**	**0.6207 ***	**0.5072**	**0.5995**
C	**PULSE ON**	**0.6095 ***	**0.5072**	**0.5905**
D	**PULSE OFF**	**0.5072**	**0.6207 ***	**0.521**

***Optimum level**

Table XII
The main effects of the factors on the grey relational grade for Mg Sic_P 20%

SYMBOL	CONTROL FACTORS	LEVEL 1	LEVEL 2	LEVEL 3
A	SPEED	0.391	0.6462	0.6478 *
B	FEED	0.489	0.639 *	0.5568
C	PULSE ON	0.4432	0.6278	0.5598
D	PULSE OFF	0.439	0.6282 *	0.5468

***Optimum level**

The optimal factor and its level combination are determined by the grey relational grade graph. Basically, the larger the grey relational grade, the better is the multiple performance characteristic. However, the relative importance among the machining parameters for the multiple performance characteristics still needs to be known, so that the optimal combinations of the machining

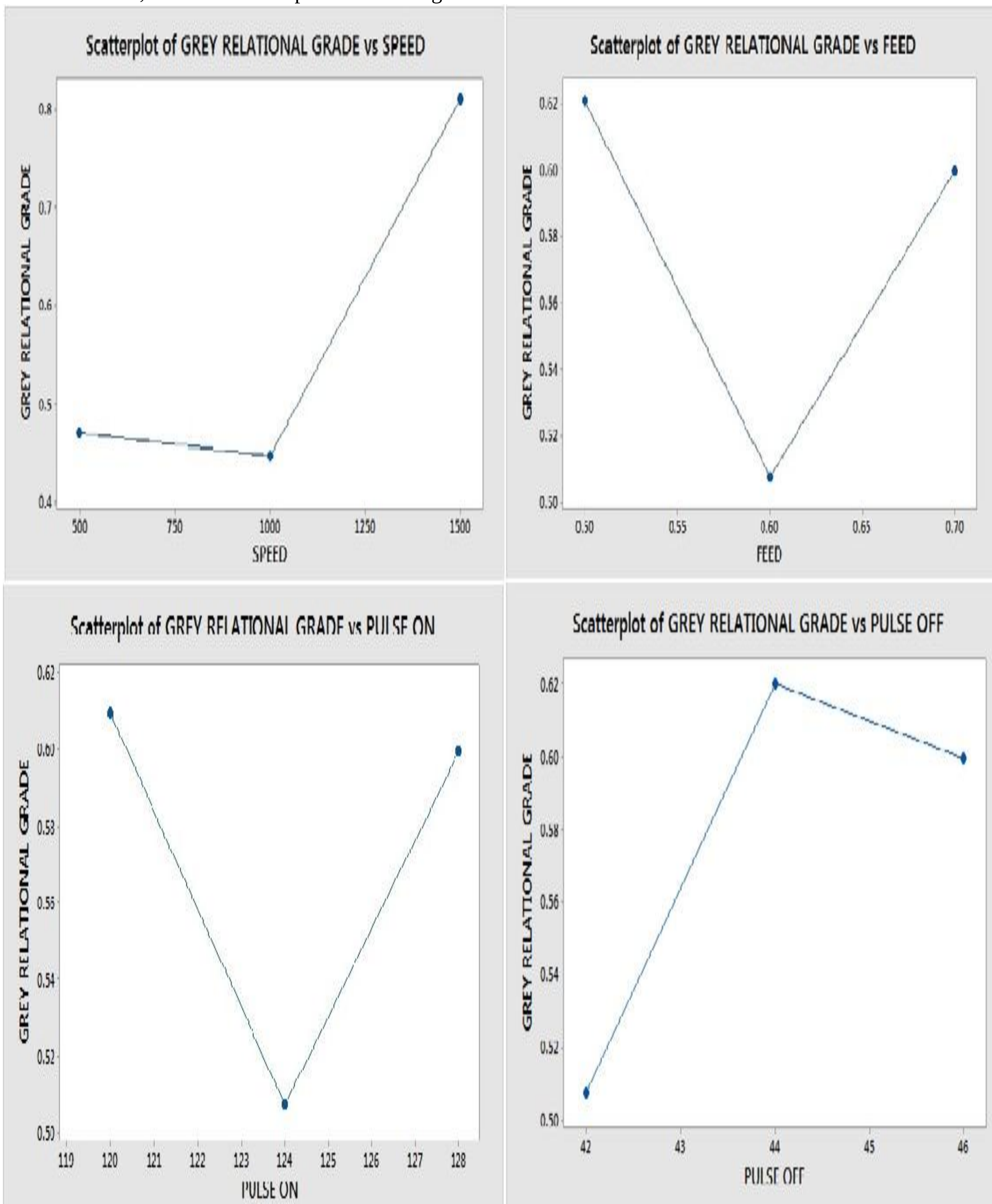

Fig. 6. Grey grade vs input parameters of Mg SiC_P 10%

The optimal factor setting obtained for the **Mg Sic_P 10%** from the graphs and table are (speed – 1500 rpm) , (feed – 0.5 mm/min) , (pulse on – 124 µs) , (pulse off – 44 µs).

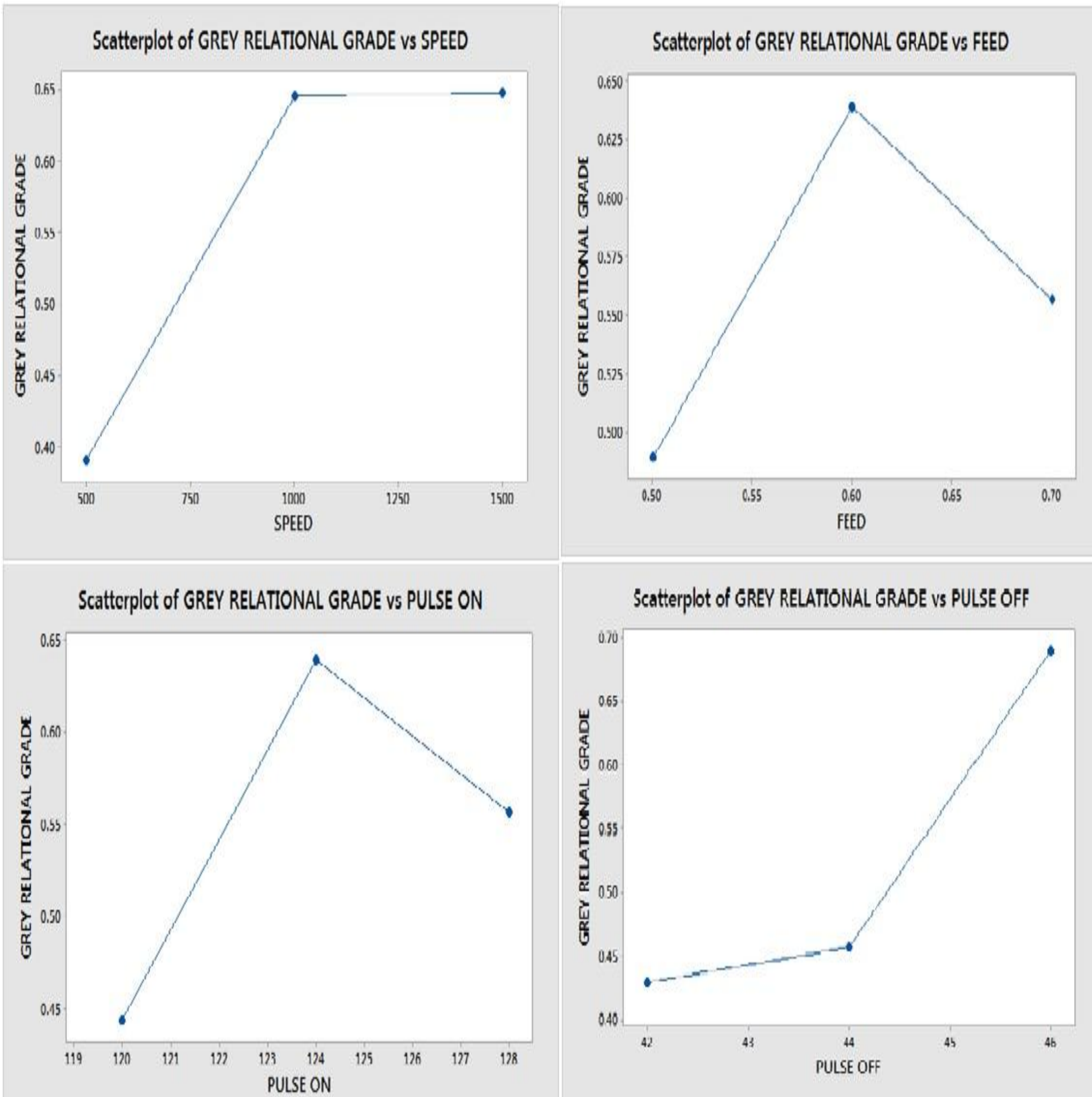

Fig. 7 . Grey grade vs input parameters of Mg Sic_P 20%

The optimal factor setting obtained for the **Mg Sic_P 20%** from the graphs and table are (speed – 1500 rpm) , (feed – 0.6 mm/min) , (pulse on – 124 µs) , (pulse off – 46 µs).

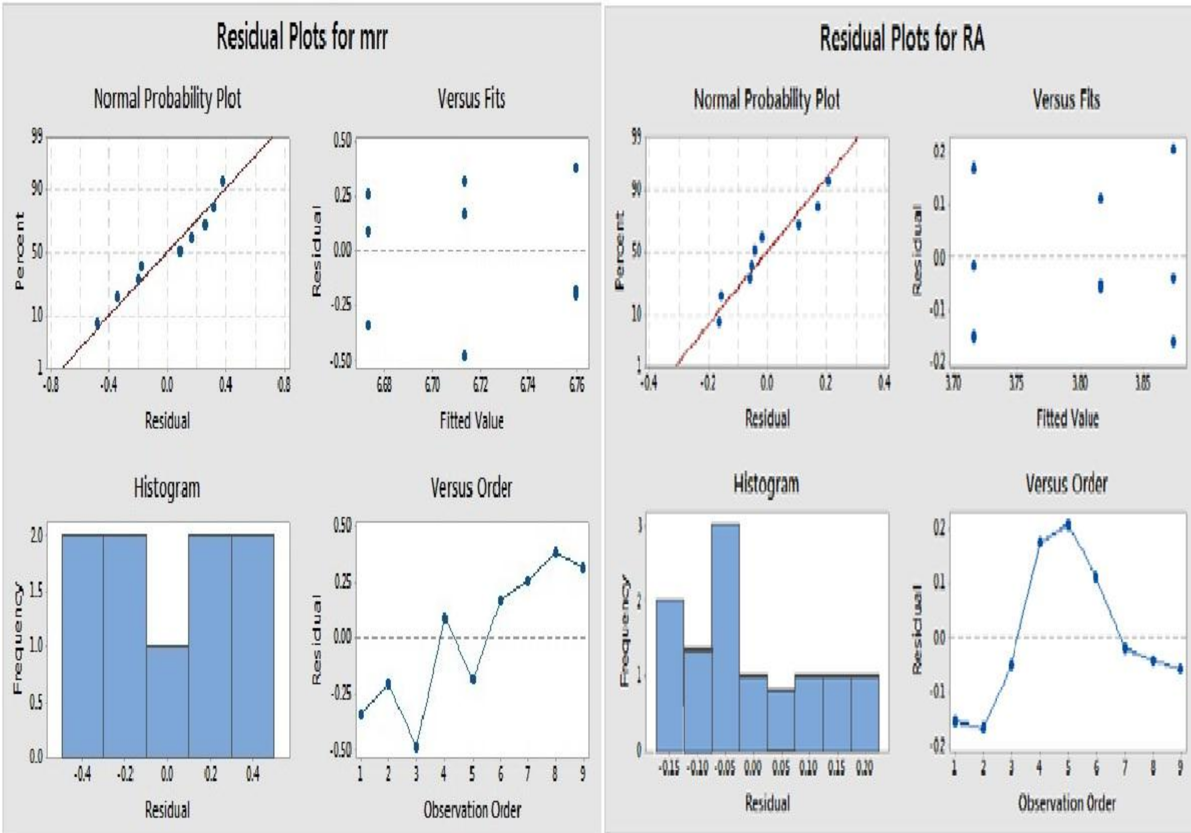

Fig. 8 . Residual plot for output parameters of Mg Sic_P 10%

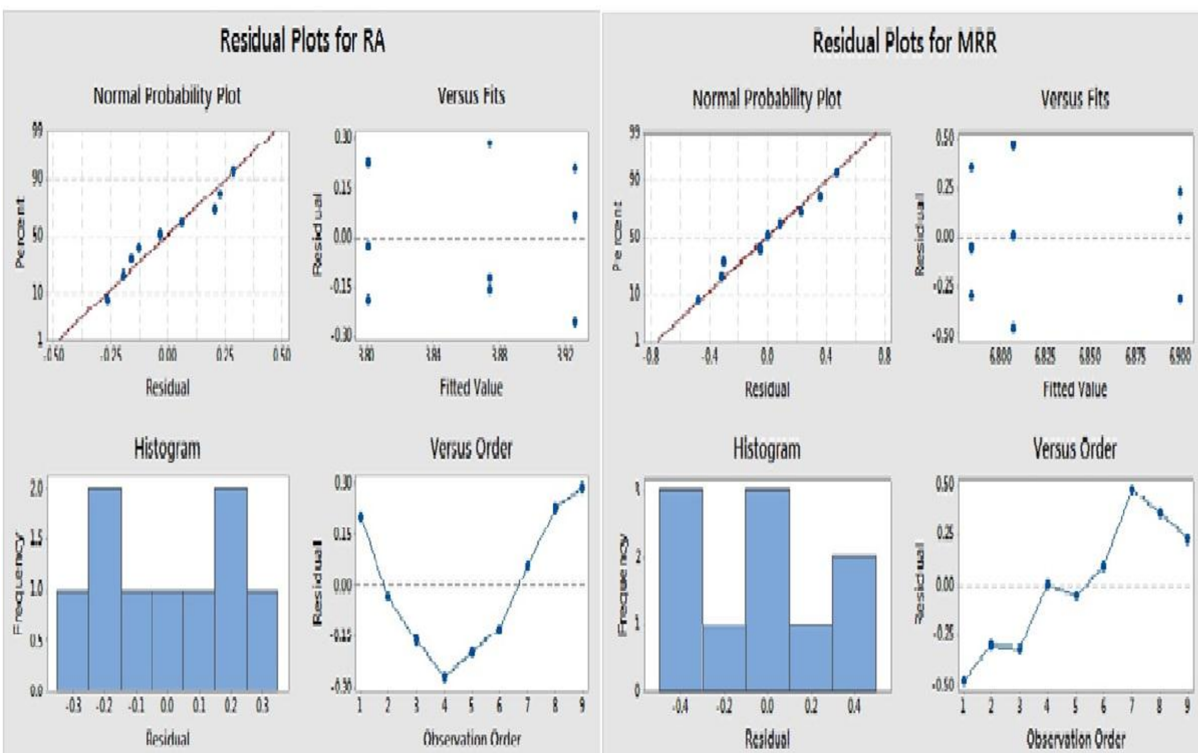

Fig. 9. Residual plot for output parameters of Mg Sic_P 20%

4. RESULTS AND DISCUSSION

The confirmation test for the optimal parameter setting with its selected levels was conducted to evaluate the quality characteristics for WEDM of Mg Sic_P10% & Mg Sic_P20% .

For Mg Sic_P10% the optimal value from the L_9 orthogonal array is (EX. NO 7) with (speed – 1500 rpm) , (feed – 0.7 mm/min) , (pulse on – 124 µs) , (pulse off – 42 µs) .were as the optimal value obtained from the Grey theory design is (speed – 1500 rpm) , (feed – 0.6 mm/min) , (pulse on – 124 µs) , (pulse off – 42 µs) .

For Mg Sic_P20% the optimal value from the L_9 orthogonal array is (EX. NO 6) with (speed – 1500 rpm) , (feed – 0.6 mm/min) , (pulse on – 124 µs) , (pulse off – 46 µs). were as the optimal value obtained from the Grey theory design is (speed – 1500 rpm) , (feed – 0.6 mm/min) , (pulse on – 120 µs) , (pulse off – 46 µs) .

Hence a confirmation experiment is conducted to find the improvements in the process and is as shown below

Table XIII
Optimal process parameters

MATERIAL	FACTOR	LEVEL	MRR (mm³/sec)	RA(µm)	Error %
Mg Sic_P10%	Orthogonal array	A3B1C3D2	7.28	3.9875	10.35
	Grey theory design	A3B2C2D1	7.93	4.234	
Mg Sic_P20%	Orthogonal array	A3B2C1D3	7.14	3.832	13
	Grey theory design	A3B1C2D3	7.74	4.102	

Above table shows that the significant machining parameters for performance measures surface roughness in the WEDM process. Factors like speed, feed, Time on and Time off have been found to play a significant role for MRR and surface roughness. Taguchi's method is used to obtain optimum parameters combination for maximization of surface roughness. The conformation experiments were conducted to evaluate the result predicted from Taguchi Optimization.

CONCLUSION

In this project, an application of combined Taguchi Method and Grey Relational Analysis, to improve the multi-response characteristics of MRR (Material Removal Rate), Surface roughness in the Wire-Cut EDM (Electrical Discharge Machining) of Mg Sic_P10% & Mg Sic_P20% has been done. As a result, this method greatly simplifies the optimization of complicated multiple performance characteristics and since it does not involve complicated mathematical computations, this can be easily utilized by the Manufacturing world.

1. The optimal process parameters based on Grey Relational Analysis for the Wire Cut EDM of Mg Sic_P10% include (speed – 1500 rpm) , (feed – 0.5

   mm/min) , (pulse on – 124 µs) , (pulse off – 44 µs).

2. The optimal process parameters based on Grey Relational Analysis for the Wire Cut EDM of Mg Sic_P20% include (speed – 1500 rpm) , (feed – 0.6

   mm/min) , (pulse on – 124 µs) , (pulse off – 46 µs).

3. While applying the Grey Taguchi method, The Material Removal Rate

   Shows an increased value of 7.28 (mm³/sec) to 7.93 (mm³/sec) . Thus, it can be concluded that the Grey Taguchi Method, is suitable for the parametric optimization of the Wire Cut EDM process, when using the multiple performance characteristics such as MRR (Material Removal Rate), Surface Roughness for machining the Mg Sic_P10% & Mg Sic_P20%.

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