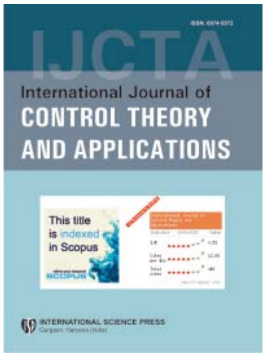

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Response Surface Modeling and Grey Relative Analysis to Optimize the Wire Edm Machining Parameters with Multiple Response Characteristics

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Abstract: The quality of machining of AA7075-PAC metal matrix composites by WEDM is investigated using response surface methodology and grey relative analysis.

Method: Experimentation is designed and performed using Response surface methodology with 27 trials discharge current, pulse on time, pulse off time and servo speed rate as input variables. Material removal rate and surface roughness are measured as responses. Results are used to optimize the parameters using Grey relative analysis. Best combination of parameters was found by grey relative analysis. ANOVA technique is used to find the influence of parameters on the responses.

Findings: Grey relation analysis yields low surface roughness and high removal rate for the combination of Discharge current 17500A, pulse on time 5µs, pulse off time 50µs and servo speed 100 rpm. Confirmation test increasing responses is performed and found to be good agreement with experimental results. Microstructure studies reveal the interfaces between the materials and the appearance of grain particles of the best combination parameters.

Improvement: Results from Grey relative analysis slightly edge over the experimental results from Response surface technique.

Keywords: *Response surface Methodology, Grey Relative analysis, Wire EDM, Metal matrix Composites.*

1. INTRODUCTION

Wire cut is a non-traditional machining process in which the material is removal by series of electrical discharges occurring between associate degree conductor and a piece immersed in an exceedingly non-conductor fluid[1]. Researchers in part of Marine and Defence applications need a cloth that offers sensible specific strength and wear resistance. Researchers, particularly within the defence application, ceaselessly attempt onerous to search out the materials that suit their specific necessities Statistical-mathematical models[2] are perpetually utilized by scientists to explain the correlation between characteristics and machining output results and setting or input parameters[3, 4]. Ravindranadh et al. has presented the effect of machining responses on various process variables.*i.e*. Material Removal rate (MRR) and Surface Roughness (SR)[5] by mistreatment Buckingham pi theorem correlation between of method parameters was derived for big MRR and tiny Ra by applying Analysis of Variance (ANOVA). Venkatesan et al.[6] characterized the machinability conditions of Al7075-Al2O3 matrix composite for multi-layer coated inorganic compound inserts. Baskarn et.al investigated the dry wear behaviour of casted AA7075-TiC[7] metal matrix composites by taguchi technique. Rajendra et.al had a survey on AA7075 Metal Matrix Composites; Pujari et al[8] developed a semi-empirical model of surface end for varied materials by developing statistical regression models within the wire discharge machining method. Habib et al[9] performed experiment supported the analysis of Taguchi's technique among totally different method parameters. Multivariate analysis is performed to see the relative magnitude of every issue on the target perform. To fulfil the higher than necessities stuff has been initiated metal matrix composites[10] in particulate strengthened MMC, reinforcement is additional to the matrix of the majority material to extend its stiffness and strength, powdered activated carbon acts as a reinforcement material[11].

Limited research has been done to develop mathematical model for MRR and Ra in wire EDM for AA7075 – PAC metal matrix composites. The production of Al 7075/PAC composite by stir casting method with three different compositions of Al7075-3%PAC, Al7075-6%PAC, Al7075-9%PAC[12]. From there the best composite has been selected based on the testing results for this wire cut machining process. Authors have made an attempt to establish the relation between the parameters by developing mathematical model and understanding the model developed for the input parameter[13]. Here the Al7075- 9%PAC metal matrix composites are used as work piece material. The aim of this analysis is to analyse the result of input variables and error rate of experimental worth and expected worth of removal rate of material and surface roughness[14]. The input parameters of EDM method like Discharge current, pulse-on time, pulse off time and servo speed were chosen. This work presents mathematical model equations area unit developed for cutting rate of material and surface irregularity and therefore the developed equations area unit utilised throughout the analysis of variance to optimize the WEDM method[15].The Composition of Aluminium alloy 7075 (5.7 % Zn, 2.4% mg, 1.6 % Cu, 0.5% Fe, 0.4% Si, 0.3% Mn, 0.2% Ti, 0.2% Cr and Al remainder) were casted with activated carbon by stir casting method.

2. MATERIALS AND METHODS

The experiments were conducted with three controllable four level factors and 3 levels. Twenty seven experiments were conducted using RSM method during this component as per the Box-Behnken style thought of as shown in Table 1. It shows four manageable factors *i.e*., discharge current (A), pulse on time (μs), pulse off time (μs), and servo speed (RPM) with 3 levels for every issue. The cutting parameters area unit set to the pre-defined levels for all the experiments. The material used for work piece was AA7075 with PAC composition metal matrix composites. The ELECTRONICA AQ550L Wire EDM tools machine was used to conduct the experiment methods. During experiment the spark is developed between incessantly move brass wire and work piece. The volume of the MRR of work piece is calculated by formulae. The Surface Roughness parameter Ra was measured by using surface roughness measuring instrument profilometer. A cylindrical rod shape brass electrode was used as the tool. Distilled water was used as a dielectric fluid. In the machine the brass electrode was used as the tool and the work piece and also the EDM machine contains a tool which is interconnected with power unit and submerged flushing unit.

Table 1
Input process parameters and their levels

Parameters	*Symbol*	*Level 1*	*Level 2*	*Level 3*	*Units*
Current	IA	1500	1750	2000	A
Pulse on	T_{on}	5	10	15	μs
Pulse off	T_{off}	25	50	75	μs
Servo speed	SS	50	100	150	RPM

2.1. Mathematical Modeling

Response surface is a technique of experiments that is useful for modeling, may be an assortment of mathematical and applied mathematics techniques by that the correlation between the response and therefore the variables are discerned to realize smart model data of response surface is incredibly essential. Solely four experimental factors that are capable of influencing the studied method yield are I_A, T_{ON}, T_{OFF} and SS. Where, I_A is the Discharge current (A), Ton is the pulse-on time (μs), Toff is the pulse-off time (μs) and SS is the servo speed (RPM).

2.2. Grey relational analysis (GRA)

In the Grey relative analysis, experimental results (MRR and SR) were initial normalized and so the Grey relative constant was calculated from the normalized experimental knowledge to specific the connection between the required and actual experimental knowledge. Then, the grey relative grade was computed by averaging the Grey relative constant reminiscent of every method response (2 responses). The general analysis of the multiple method responses relies on the Grey relative grade. As a result, optimisation of the sophisticated multiple method responses may be regenerate into optimisation of one Grey relative grade. In different words, the Grey relative grade may be treated because the overall analysis of experimental knowledge for the multi response method. Optimisation of an element is that the level with the very best Grey relative grade[16].

2.2.1. Grey relational generation

GRA is categorized into three types namely Lower the better, Higher the better criterion. In the study, a linear data preprocessing method for the MRR is the higher-the-better [6] and is expressed as:

$$X_i^* = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

Similarly the normalized data processing for SR is lower the better can be expressed as:

$$y_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

Where $i = 1,2,\ldots.m$; $k = 1, 2,\ldots.n$; m = no of experimental data; n = no of factors; $y_i(k)$ = original sequence; $y_i(k)$ value after grey relational generation; min $y_i(k)$ and max $y_i(k)$ are the minimum and maximum value of $y_i(k)$ respectively. The normalized values are shown in table 4.

2.2.2. Grey relational coefficient

The calculation for grey relation coefficient was done using equation (3)

$$\in_i(k) = \frac{\Delta\min + \omega\Delta\max}{\Delta_{oi}(k) + \omega\Delta\max}$$

Where $\varepsilon_i(k)$ is the grey relation coefficient. Δ_{oi} is deviation among $y_0(k)$ and $y_i(k)$; $y_0(k)$ is the ideal sequence; Δmax is highest value of $\Delta_{oi}(k)$; Δmin is least value of $\Delta_{oi}(k)$.

2.2.3. Grey relation grade

The Grey relation grades square measure determined by taking average of the Grey relation constant associated with each observation as bestowed in equation (4).

$$\Gamma_i = \frac{1}{M}\sum_{=1}^{Q} i(k)$$

Where Q is total quantity of responses and *n* denotes the quantity of output responses. The Grey relative grades represent level of relationship between among the reference and therefore the comparative sequence. If larger Grey relative grade is obtained for the equivalent set of process parameters compared to other sets, it is considered as the most favorable optimal setting.

3. RESULTS AND DISCUSSION

The results of performance measures MRR, SR are obtained for twenty seven experiments trials of machining data are given in the column. The reactions of four input process parameters and their effects on MRR and SR is analyzed and studied exploitation the experimental values. An effort has been taken to determine the best possible set of machining parameters for machining the metal matrix composite effectively.

Table 2
Experimental design using box Behnken response surface method

Exp No	*IA*	*Ton*	*Toff*	*SS*	*MRR (mm3/min)*	*SR (µm)*
1.	1750	5	50	150	9.54	3.37
2.	1750	10	75	50	6.84	4.03
3.	1500	10	75	100	8.2	3.79
4.	2000	10	50	150	7.99	3.43
5.	1750	10	50	100	8.82	3.69
6.	1750	10	50	100	8.82	3.69
7.	1750	10	25	150	10.8	3.54
8.	1500	10	50	150	10.26	3.71
9.	1500	15	50	100	8.45	3.83
10.	1750	5	75	100	7.56	3.32
11.	2000	15	75	100	9.66	3.72
12.	2000	5	75	150	9.6	3.3
13.	1750	15	75	100	8.14	4.01
14.	1750	10	25	50	9.36	3.71
15.	1750	5	50	100	9.62	3.11
16.	1750	15	50	150	11.1	3.71
17.	1750	10	75	100	8.34	3.63
18.	2000	10	25	50	8.04	3.68
19.	1750	5	50	100	8.04	3.47
20.	1750	5	25	100	8.58	3.43
21.	1750	15	75	50	11.62	3.66
22.	2000	10	50	100	7.98	3.53
23.	1500	15	50	100	9.57	4.01
24.	1500	10	25	100	9.31	3.47
25.	1500	10	50	50	6.98	4.05
26.	1750	10	50	100	8.82	3.89
27.	2000	10	75	100	8.64	3.57

3.1. Effects of process Parameters on MRR

The Table three that explains that the MRR tends to extend to increasing level of on time and speed rate then ends up in high rate of wire EDM which ends within the high material rate. Equally MRR is low once the heartbeat off time is 10µs and Discharge current is 1500A.The mathematical model foreseen values and also the experimental values of MRR are compared with one another and diagrammatically shown within the Fig. 1. It's studied that the key influencing parameters are pulse on, servo speed to most MRR and also the minor influencing parameters aredischarge current and off time parameters influencing minimum removal of material.

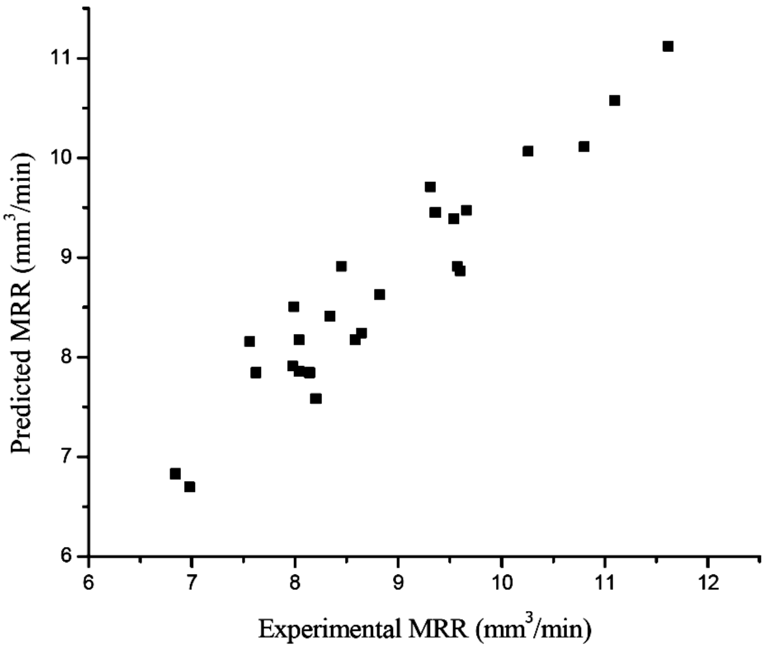

Figure 1: Comparison between experimental MRR and Predicted MRR using Mathematical modeling

3.2. Effects of process Parameters on SR

The experimental data continues to increase surface irregularity decreases because the on time and off time increases. But roughness of material is low once on time is 5µs and Discharge current is 2000A.The mathematical model foretold values and therefore the experimental values of SR square measure compared with one another and diagrammatically shown within the Fig. 2. It's studied that the foremost influencing parameters square measure pulse on, pulse off time to most SR and therefore the minor influencing parameters square measure Discharge current and servo speed to supply minimum MRR.

3.3. Analysis of Variance

Analysis of variances has been performed and the P-value for every model in, mentioned tables is a smaller amount than 0.05, indicating that for a confidence level of 92.5%, the models are statistically vital and terms within the model have the many impact on the responses. The final response equation for various performance measures like MRR, SR and Grade is given as follows:

$$MRR = -8.9 + 0.0226 I_A - 0.433 T_{ON} - 0.221 T_{OFF} + 0.0926\, SS - 0.000008\, I_A * I_A + 0.0078\, T_{ON} * T_{ON} + 0.000488\, T_{OFF} * T_{OFF} + 0.000016\, SS * SS + 0.000469\, I_A * T_{ON} + 0.000087\, I_A * T_{OFF} - 0.000045\, I_A * T_{ON} - 0.00409\, T_{ON} * T_{OFF} - 0.00417\, T_{ON} * SS + 0.000401\, T_{OFF} * SS$$

$$SR = .41 - 0.00115\, I_A - 0.0296\, T_{ON} + 0.0102\, T_{OFF} - 0.01065SS + 0.00000\, I_A * I_A\, 0.00162\, T_{ON} * T_{ON} - 0.000015\, T_{OFF} * T_{OFF} + 0.000008\, SS * SS + 0.000034\, I_A * T_{ON} - 0.000004\, I_A * T_{OFF} + 0.000004\, I_A * SS + 0.000149\, T_{ON} * T_{OFF} + 0.000126\, T_{ON} * SS - 0.000006\, T_{OFF} * SS$$

$$Grade = 0.5623 + 0.0276\, A1 - 0.0009\, A2 - 0.0266\, A3 - 0.0100\, B1 + 0.0193\, B2 - 0.0093\, B3 - 0.0749\, C1 + 0.0220\, C2 + 0.0528\, C3 + 0.1568\, D1 - 0.0439\, D2 - 0.1130\, D3$$

After cutting two quality objectives were chosen, including removal rate of material and surface irregularity. The review of the model is incredibly abundant necessary once the analysis of knowledge. Within the response equation the A represents Discharge current, B represents Pulse on time, C represents and D represents servo speed. ANOVA is performed and predicted for MRR and for SR also.

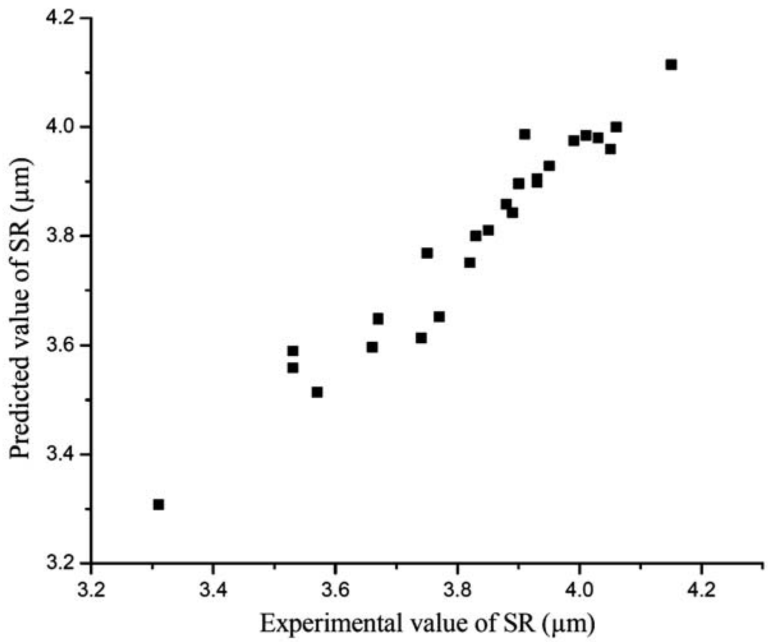

Figure 2: Comparison between experimental SR and Predicted SR using Mathematical modeling

The average grey relational grade value for every level of the input parameters is given in table 3. These have been calculated by taking the average for each level group in all the levels of process parameters. Since it denotes the level of correlation between reference sequence and obtained sequence, the higher value of average grey grade indicates stronger correlation between them. It represents best level of method parameters is A1B3C3D1, which implies the experiment gives most influencing parameters based on their responses. Fig 3 shows the main effect plot of Grey relation grade.

Table 3
Analysis of variance for grade

Source	*DF[a]*	*Seq SS[b]*	*Adj SS[d]*	*Adj MS[c]*	*F*	*P*	*% Contribution*
IA	2	0.014672	0.007724	0.003862	0.67	0.523	3.5243
Ton	2	0.054051	0.00507	0.002535	0.44	0.65	13.0936
Toff	2	0.041542	0.057846	0.028923	5.04	0.018	9.9788
SS	2	0.284986	0.172981	0.08649	15.07	0	68.4558
Error	18	0.021201	0.010332	0.00574			
Total	26	0.416308					

Table 4
Grey relational coefficient and grade of each performance characteristics

Exp No	*Coefficient of MRR*	*Coefficient of SR*	*Grade*
1.	0.469548134	0.36	0.414774067
2.	1	0.692307692	0.846153846
3.	0.637333333	0.627906977	0.632620155
4.	0.799331104	0.551020408	0.675175756
5.	0.546910755	0.509433962	0.528172359
6.	0.546910755	0.509433962	0.528172359
7.	0.376377953	0.397058824	0.386718388
8.	0.411359725	0.473684211	0.442521968
9.	0.669467787	0.457627119	0.563547453
10.	0.768488746	0.45	0.609244373
11.	0.458733205	0.574468085	0.516600645
12.	0.46407767	0.333333333	0.398705502
13.	0.647696477	0.658536585	0.653116531
14.	0.486761711	0.473684211	0.480222961
15.	0.753943218	1	0.876971609
16.	0.359398496	0.529411765	0.44440513
17.	0.614395887	0.551020408	0.582708148
18.	0.665738162	0.5	0.582869081
19.	0.665738162	0.415384615	0.540561388
20.	0.578692494	0.391304348	0.484998421
21.	0.333333333	0.482142857	0.407738095
22.	0.532293987	0.457627119	0.494960553
23.	0.466796875	0.75	0.608398437
24.	0.491769547	0.519230769	0.505500158
25.	0.829861111	0.72972973	0.77979542
26.	0.546910755	0.509433962	0.528172359
27.	0.570405728	0.490909091	0.530657409

ANOVA is a method of computation When we have only two responses we can used to compare the means of the variables but it might become unreliable in case of more than two samples. Here two responses compared, and then the independent samples will give the same results as the ANOVA. The significant process parameters are determined by ANOVA analysis. Minitab17.0 statistical software is used to analyze the significance of machining parameters. ANOVA is calculated using Grey relational grade for analyzing the importance of process parameters. From analysis of variance it was clear that the servo speed (68%) influences most in determining the quality of the MRR and SR and it's followed by pulse on time (13%) then pulse off time (10%) and discharge current (4%). ANOVA table shows that the results are closely related with grey relational analysis. The outcomes of ANOVA for grade are shown in Table 3.The contribution of WEDM process parameters on the output response is shown in fig 4.

Table 5
Response table for grey relation grade

Symbol	*Parameter*	*level 1*	*level 2*	*level 3*	*Main effect*	*Rank*
A	IA	0.58873	0.55414	0.35332	0.235415	2
B	Ton	0.48966	0.5683	0.58154	0.091883	4
C	Toff	0.47468	0.54572	0.62742	0.152745	3
D	SS	0.74778	0.53389	0.46038	0.287398	1

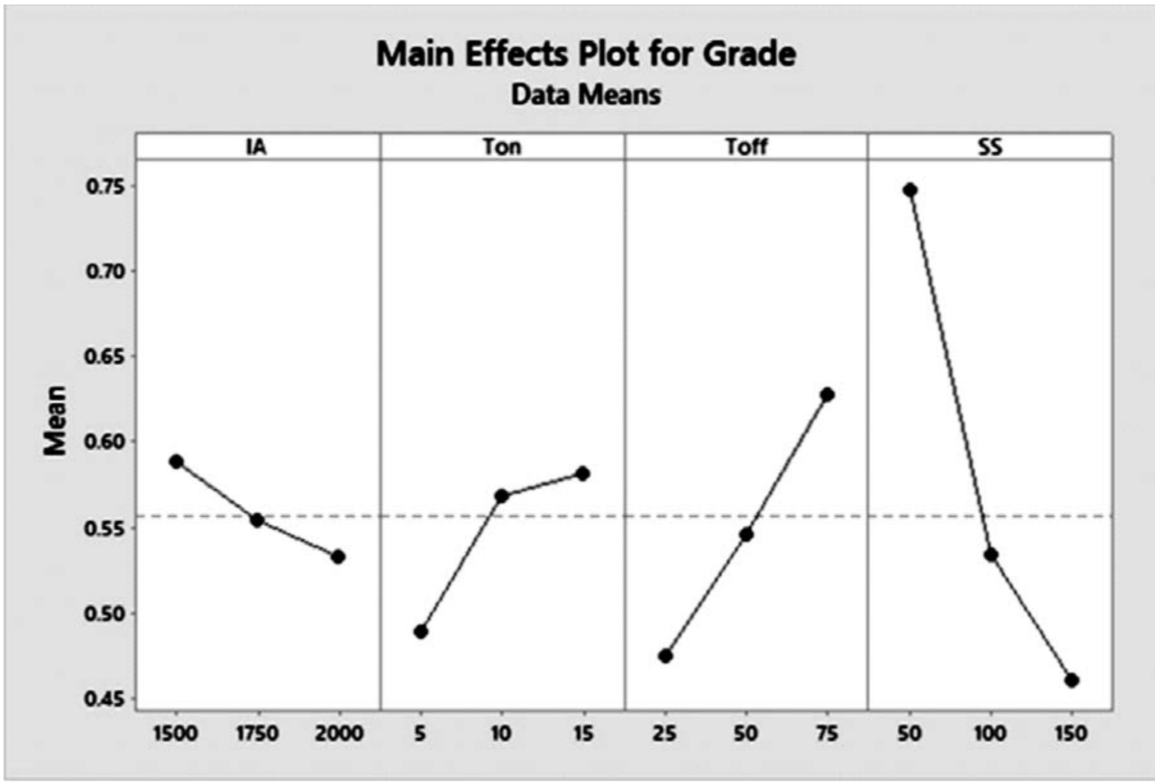

Figure 3: Main effect plot of grey relation grade

3.4. Confirmation check

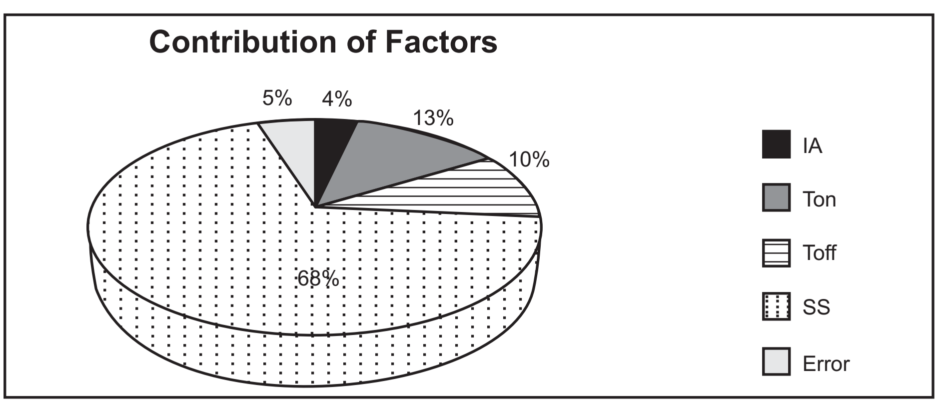

Figure 4: Contribution of factors

When distinguishing the input parameters, the ultimate section is to verify the Removal Rate and also the surface roughness by conducting the confirmation experiments. The A1B3C3D1 is a best parameter combination throughout WEDM method via the Grey relative analysis. Therefore, the condition A2B3C3D1 of the best parameter combination was treated as confirmation check. The combination of best parameters was chosen to conduct experiment for efficient and quality Wire cut electrical discharge machining process.

3.5. Microstructure analysis

The microstructure of the optimal parameter grade for experiment is shown in fig 5. The microstructure for experiment shows very clean grain confines with the existence of reinforcement particles uniformly distributed along the grain confines are observed. The grain sizes are found to be relatively decreased with maximum amount of activated carbon particles. The interfaces between aluminium 7075 and PAC particles are very clearly observed along the grain confines with the appearance of some particles mixed inside the matrix material.

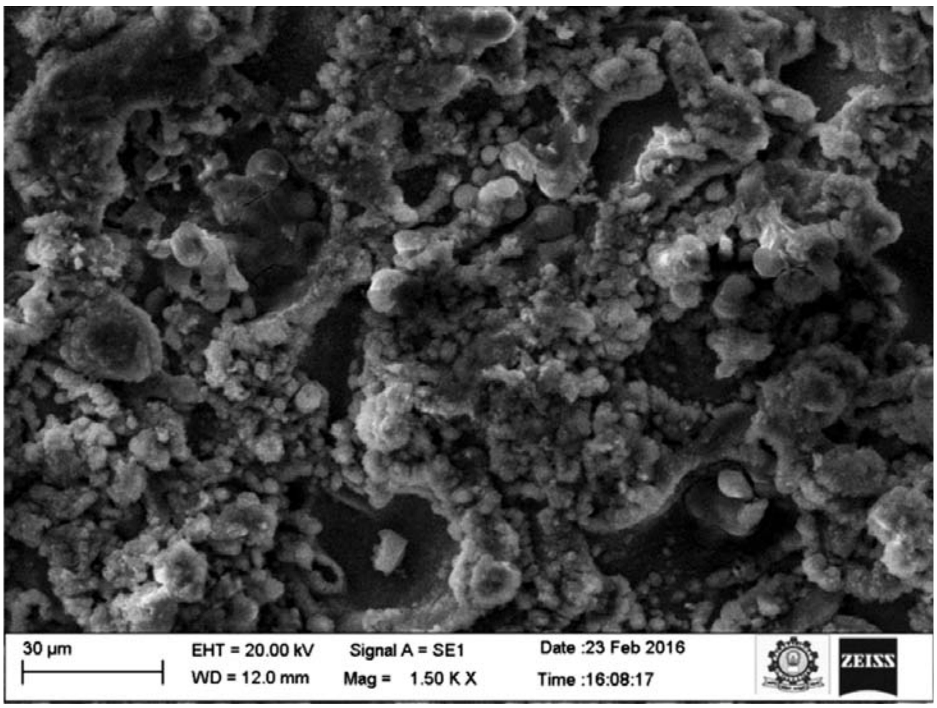

Figure 5: Microstructure of optimal grade parameter Experiment

4. CONCLUSION

Using RSM method 27 experiments are conducted in wire cut Edm process. The results of responses are used for Grey relative analysis supported the response surface methodology table was used to optimize the WEDM method parameters for MMC. An optimum combination of four test parameters of grey relational grade for high removal of material and low surface roughness was found to be discharge current 1750A, on time 5µs, off time 50µs and servo speed 100rpm. Based on the ANOVA results of grey relational analysis, it was observed that the servo speed (68%) contains a maximum influence responses followed by on time (13%) then the off time (10%) and discharge current (3%). Mathematical models were developed using response surface method for MRR, SR and Grade to determine the relation between variables and performance measures. Optimum response characteristics such as MRR, SR are improved with 5% error by employing Grey relational analysis. The microstructure of best combination experiment suggests that machining of MMC produces with smaller grain size and there is a good matrix interface bonding.

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