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Effect of material and machining features in electric discharge machining of 6061Al/rock dust composites

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The current research investigates the effect of electric discharge machining (EDM) and material parameters on material removal rate (MRR), tool wear rate (TWR) and surface roughness (Ra) while machining the novel aluminium rock dust composite. Experiments have been performed in Vidyunt EM 150 EDM machine by considering parameters namely discharge current, pulse ON time, pulse OFF time, reinforcement size and level. The composites have been prepared through stir casting method by reinforcing various sizes (10, 20 & 30 µm) of rock dust particles with aluminium 6061 and at different levels (5, 10 & 15%). Since the number of input parameter is more, Taguchi's design of experiments has been used to reduce the number of trials and grey relational analysis (GRA) technique has been used for optimization. Analysis of variance has been performed to identify the significance of the parameters and it has been found that all the considered parameters have significant effect on response variables. But in the case of multi performance characteristics analysis, only pulse ON time and pulse OFF time have the significance over GRG. Pulse ON time has the highest influence (55.36 %) on the GRG followed by pulse OFF time with 17.6% and rock dust weight % with 7.8%. From the confirmation experiments, it could be well said that the developed regression equations predicts the response parameters with minimal error and the grey relational grade has been improved significantly.

Keywords: EDM, Silica, Rock dust, Taguchi, GRA, Optimisation

1 Introduction

Modern industries motivate the use of advanced unconventional materials (composites, ceramics and super alloys) for weight reduction and performance increment. These industrial requirements demands materials with a definite set of properties, which leads to the invention of composite materials consisting of two or more chemically and/or physically different phases. The matrix is continuous phase and the discontinuous phase is called as reinforcement. Matrixes consisting of a metallic base, usually a ductile metal (e.g. Al, Mg or Ti) is reinforced with ceramic elements (e.g. SiC, Al_2O_3 or graphite) to produce metal matrix composites (MMCs). These advanced unconventional materials have greater properties than those exhibited by any of its individual constituents. Conversely the poor machinability and excessive tool wear during the traditional machining of these potential materials hinders their applications. Hardness, non-homogeneity, anisotropy, low ductility, toughness and inherent brittleness results in the aforesaid problems[1]. In lieu of all these concurrent liabilities, unconventional machining techniques like that of EDM have to be effectively employed for trouble-free machining of AMMCs[2-10].

EDM can be done for the electrically conductive materials of any hardness. Since there is no contact between electrode and work piece, no tools force is generated. So, it offers independence to design the various attachments or mechanisms that will help to move the electrode in complex paths and consequently some intricate shapes can be produced[11]. The complete literature study given in this section (Table 1) is focused on experimental studies carried on the electric discharge machining of AMMC that deals majorly with a variety of machining features.

Finally from the literature it is obvious to state that researchers identify EDM technique (proven for its merit in the machining of MMCs) for gaining improved MRR, less TWR and better surface finish. These investigations mainly fall in the area of optimization of EDM parameters during AMMCs machining and only few studies considered the material parameters. Hence, this

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Table 1 — Literatures on EDM of AMMC.

Authors	Material	Findings
Gopalakannan S & Senthilvelan T[3]	Al/SiC$_p$	• Pulse current, pulse OFF time and pulse ON time have effect on MRR wherein voltage remains insignificant. • The higher pulse OFF time offers lower electrode wear rate (EWR) value. • The EWR and surface roughness (R$_a$) increases with increase in pulse ON time and pulse current for every value of voltage
Riaz Ahamed A *et al.*[4]	Al/SiC$_p$/B$_4$C$_p$ & Al/SiC$_p$/Glass$_p$	• The existence of ceramic reinforcement particles in the MMC is a barrier for machining. • Quite extended spark duration is needed to remove the material in Al–SiCp–B$_4$Cp with larger value of flushing pressure and adequate time for the dielectrics • Slight higher ON time and reduced flushing pressure is needed for Al–SiCp–Glass$_p$ machining which is reliant on the wettability between the matrix and the reinforcements
Egashira K *et al*.[5]		• EDM parameters have great effect on the microstructure of machined area but no effect on other regions. • Higher voltage produces porosity and non uniform surface in the machined area owing to increased local energy.
Mehdi Hourmand *et al.*[6]	Al-20Mg$_2$Si	• Discharge gap leads to some changes in surface roughness.
Velusamy Senthilkumar & Bidwai Uday Omprakash[7]	Al/TiC	• The reinforced ceramic particles (TiC) has not melted during the process and material removal occurs as an effect of matrix melting and ceramic reinforcement particle pull out thereafter. • This occurrence consequences in reduced MRR for increased TiC content of composite material composition.
Mathan Kumar N *et al.*[8]	AL2618 / Si$_3$N$_4$, AlN and ZrB$_2$	• Hence it could be well said that MRR and TWR are influenced by discharge current. • The composite composition is the main influencing process parameter for MRR and the additions of reinforcement have decreased MRR to a certain extent. • TWR decreases when the amount (wt. %) of reinforcement in the matrix is increased during EDM.
Paras Kumar & Ravi Parkash[9]	Al/B$_4$C	• The current and pulse-on time is the most significant parameters for surface roughness during EDM. • The roughness of the composite surface during ED machining increases with an increase in current • R$_a$ decreases with pulse-off time up to a minimum level and then remains almost constant.
Debaprasanna Puhan *et al.*[10]	Al/SiCp	• Discharge current, duty factor, flushing pressure and pulse-on-time have the considerable on multi performance characteristic (MPCI). • Mesh size and weight percentage of reinforced SiC has relatively less effect on improving MPCI. • The difficult-to machine material can be easily machined through EDM in the company of improved quality characteristics.
Singh S[1]	Al/Al$_2$O$_{3p}$/20$_P$	• The pulse current has the tenacious effect among the other process parameters used to study the multi-performance characteristics. • GRA approach could be applied productively to other processes in which performance meausres are find out by many process parameters at multiple quality requests.

study aims to optimize the EDM and material parameters namely reinforcement size and weight percentage during EDM of Al/Rock dust composites. The current research employs Taguchi method for designing the experiments due to its realism in designing high quality systems that gives much-condensed variance for experiments with optimal setting of control (process) parameters[12]. Further, in the course of grey-Taguchi method it is feasible to build up a relationship between the preferred and actual experimental data and the multi objectives can be transferred into single grey grades. With the aid of the calculated grey relational grades, optimal process parameters can be identified[13]. Hence this study utilizes grey relational analysis for multi objective optimization.

2 Materials and Methods

2.1 Material preparation

Aluminium 6061 T6 base metal is purchased directly from the market and the rock dust is collected from quarries. Through EDAX the constituents of rock dust obtained are as illustrated in Fig. 1(a) and

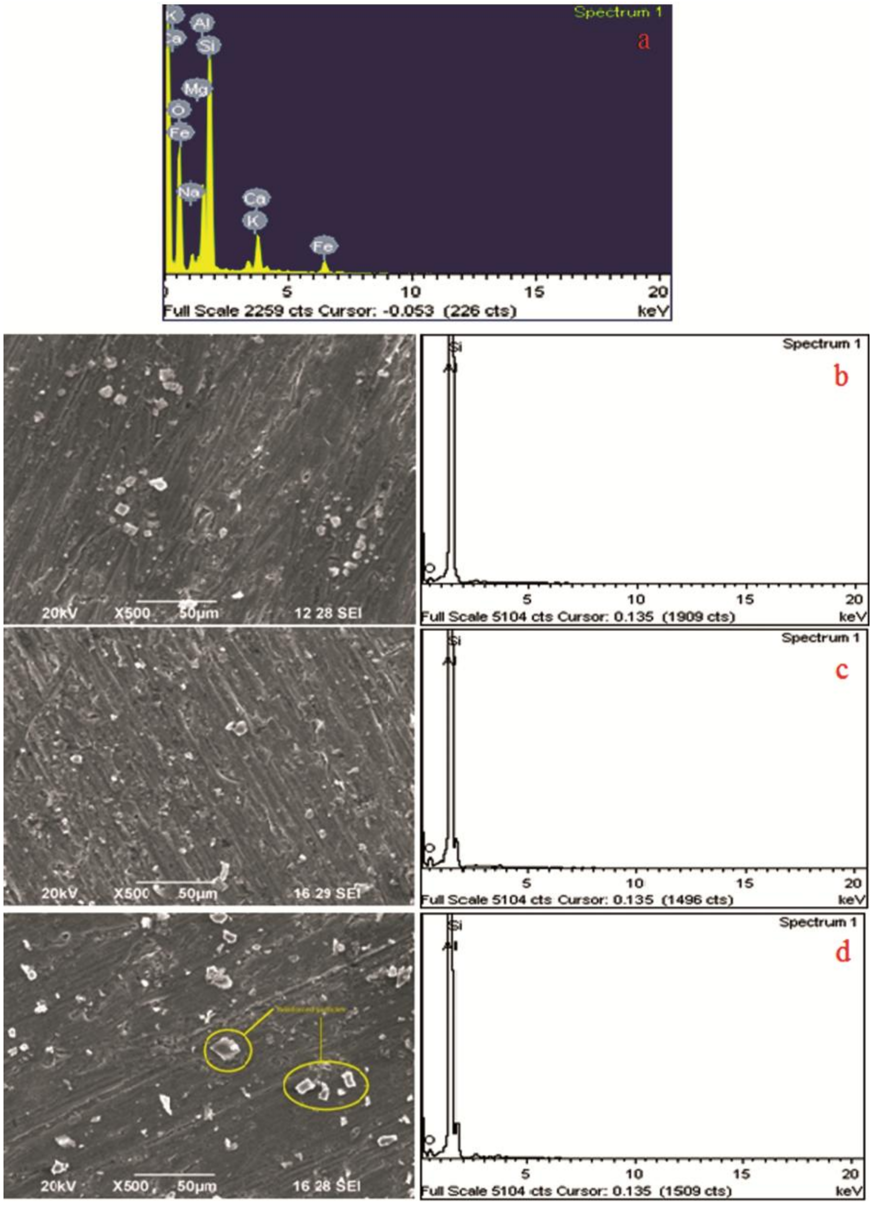

Fig. 1 — SEM micrograph and EDAX pattern of (a) Rock dust (b) Al-5%Rockdust (10µm) MMC (c) Al-10%Rockdust (20µm) MMC and (d) Al-15%Rockdust (30µm) MMC.

yet again the extracts shown here as Table 2 clarifies to the research community that rock dust composition is comparable besides possessing good probables for being a contender amongst the available reinforcement. Rock dust is a potential material for developing high performance MMC with better properties. Aluminium MMC reinforced with rock dust particles gives improved wear resistance with increase in rock dust percentage and it can be well utilized in manufacture of brake component like automobile accessories[14]. The reinforcement particles were ball milled to reduce the particle size and by varying milling time rock dust particles of three different sizes were obtained. The composites were prepared through stir casting method where the base metal is heated up to 720 ^{o}C in a graphite crucible and a measured quantity of preheated reinforcement is poured into the molten metal. Then the mechanical stirrer connected with variable speed motor is used to stir the mixture for uniform distribution of reinforcements. Wettability agent used in this study is 2% magnesium. After stirring, the mixture is poured into a rectangular die to get the required composite. This process is repeated to fabricate the remaining

Table 2 — Chemical composition of rock dust and rival materials.

Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	TiO_2	Na_2O	MgO	LOI	Others
Rice Husk Ash[15](wt. %)	94.04	0.249	0.136	0.622	2.49	-	0.023	0.442	2.05	-
Bagasse Ash[16](wt. %)	78.39	12.93	1.91	2.33	3.53	0.49	-	-	-	0.42
Fly Ash[17](wt. %)	15–45	20–25	4–15	15–40	-	-	-	-	0–5	~
Cenosphere[18](wt. %)	55	31	5	0.5	5	1	1	-	-	1.5
Rock Dust (wt. %)	51	18.4	9.29	10.2	0.59	0.78	2.1	]]]]5	-	2.64

Table 3 — Process parameters.

Parameters	Notation	Unit	Level 1	Level 2	Level 3
Discharge Current	C	A	10	20	-
Pulse ON Time	N	µs	10	30	50
Pulse OFF Time	F	µs	4	6	8
Particle size	S	µm	10	20	30
Weight percentage	W	%	5	10	15

composites by varying rock dust size (10, 20 & 30 µm) and weight percentage (5, 10 & 15 wt. %). The composites are removed from the die and grounded for attaining flat surface. Microstructure of the composite is analyzed through SEM equipped with EDS and hardness is measured through brinell hardness tester.

2.2 Machine and machining conditions

Based on the thorough view over the literature two machining parameters with three level; and one parameter with two levels along with mandatory material parameters were considered. The parameters considered for the current study with their range is given in Table 3. Range for the respective parameters was fixed based on the preliminary trial experiments. The response parameters considered to assess the machining performance is material removal rate (MRR), Surface Roughness (Ra) and Tool Wear Rate (TWR). MRR and TWR are measured by weighing the initial and final weight of work piece and tool, respectively. R_a is measured by using Mitutoyo SJ401 surface roughness tester.

Experiments were performed in Vidyunt EM 150 EDM machine and the complete detail of the machine is given in the Table 4. All the experiments were repeated three times and the average response value is taken account. The dielectric fluid used for the experiment is kerosene and the tool material used is copper with the aspect ratio of 1.

2.3 Experiment design

Experiments were designed based on Taguchi orthogonal array technique and appropriate design was selected by calculating total degrees of freedom. The current study has one factor with two levels and four factors with three levels, so the total degrees of freedom are 9. Hence L18 orthogonal array with eighteen rows and five columns were selected and the same is shown in Table 5. This partial factorial design requires only 18 experiments to study the entire parameters considered which saves both time and cost when compared to full factorial design.

Table 4 — Machine specification.

Sl.No	Particulars	Dimension
1	Work tank	600 X 370 X 280 mm^3
2	Maximum job weight	100 kg
3	Maximum job height	200 mm
4	Maximum electrode weight	50 kg
5	Z- Axis transverse	150 mm
6	Type of table assembly	Needle Roller Bearing
7	Table transverse	220 X 150 mm^2
8	T slot size	10 mm
9	Model	Vidyunt EM 150

2.4 Grey relational analysis

Grey relational analysis (GRA) is commonly used method to solve the multi performance characteristic problems[19,20]. GRA integrated with Taguchi method is used in this study to optimize the process parameters by considering multi performance measures like MRR, Ra and TWR. GRA method has four important steps (equation 1 to 4) to solve the problems which are explained as follows

Initial step in GRA is to normalize the measured response variables based on two conditions smaller is better and larger is better. Linear normalization step is

Table 5 — L18 array with MRR, TWR and Ra.

Trial No	Process parameters					Response		
	Discharge current (A)	Pulse ON time (μs)	Pulse OFF time (μs)	Particle size (μm)	Weight %	MRR (mm^3/min)	TWR (mm^3/min)	Ra (μm)
1	10	10	4	10	5	35.589	0.563	3.111
2	10	10	6	20	10	24.647	0.416	3.181
3	10	10	8	30	15	21.148	0.192	3.825
4	10	30	4	10	10	40.13	0.776	4.259
5	10	30	6	20	15	30.548	0.562	4.189
6	10	30	8	30	5	35.599	0.39	3.298
7	10	50	4	20	5	52.547	0.915	5.706
8	10	50	6	30	10	38.745	0.688	6.326
9	10	50	8	10	15	40.026	0.665	5.437
10	20	10	4	30	15	58.541	0.82	6.026
11	20	10	6	10	5	63.588	0.89	3.787
12	20	10	8	20	10	61.026	0.664	4.359
13	20	30	4	20	15	68.015	1.026	6.188
14	20	30	6	30	5	66.126	0.905	5.297
15	20	30	8	10	10	67.256	0.896	5.239
16	20	50	4	30	10	70.054	1.201	8.949
17	20	50	6	10	15	76.528	1.059	6.746
18	20	50	8	20	5	74.049	1.024	5.959

also called as ‘grey relational generating’. The values in the range between 0 (black) and 1 (white) will be obtained after the normalization.

The smaller the better normalization mode for TWR and Ra can be stated as:

$$y_i^*(k) = \frac{max\ x_i^0\ (k) - x_i^0\ (k)}{max\ x_i^0\ (k) - min\ x_i^0\ (k)} \quad \ldots (1)$$

The higher the better normalization mode for MRR can be stated as:

$$y_i^*(k) = \frac{x_i^0\ (k) - min\ x_i^0\ (k)}{max\ x_i^0\ (k) - min\ x_i^0\ (k)} \quad \ldots (2)$$

where $x_i^0(k)$ is the value to be normalized. Min $x_i^0(k)$ and max $x_i^0(k)$ are the minimum and maximum values among the particular response.

Second step is to calculate the grey relational coefficient (GRC). Grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results.

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(k) + \zeta\Delta_{max}} \quad \ldots (3)$$

where $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence. ζ is distinguishing or identification coefficient that has the value between 0 and 1. Generally $\zeta = 0.5$ is used.

Third step in GRA is calculation of grey relational grade (GRG)

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad \ldots (4)$$

In this step the multi objective problem is converted into single objective. Normally the average of the grey relational coefficient is taken as the grey relational grade. Based on the GRG value the rank is assigned and the trial which has highest GRG is considered as best. Optimal parameters can be obtained by calculating mean GRG for each parameter level.

3 Results and Discussion

3.1 Microstructure and Mechanical Properties

SEM images of the developed novel aluminium rock dust composite are shown in Fig. 1(b-d). Upon the clear view over the images, presence of rock dust particles can be identified and EDS images confirms the presence of rock dust through increase in Si peak. Hardness of the composite increases with increase in amount of rock dust particles and its size as shown in Fig. 2. Addition of foreign particles hinders the dislocation motion during deformation hence the hardness increases[21]. Generally smaller particles gives better results than larger particles but the agglomeration tendency of smaller particles due to large surface area leads to the performance decrement. Uniform distribution of reinforcements plays important role in property enhancement. It can be clearly observed from the SEM images shown in Fig. 1(b-d) that the larger particles distributed more

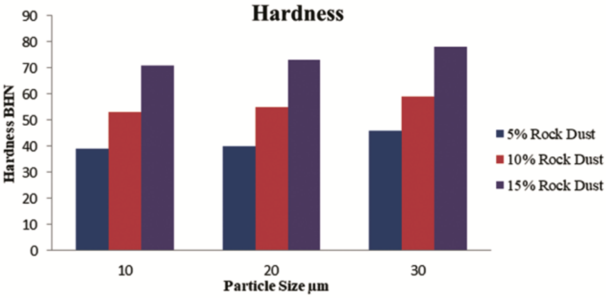

Fig. 2 — Effect of particle size and weight % on hardness.

uniformly (Fig. 1d) in the matrix when compared to smaller particles (Fig. 1b). So the hardness of the composite increases with increase in rock dust particle size.

3.2 Machining Characteristics

3.2.1 Effect of process parameters on response variables

From the Main Effect plot for MRR shown in Fig. 3 it can be noted that MRR during EDM increases with increase in discharge current and pulse

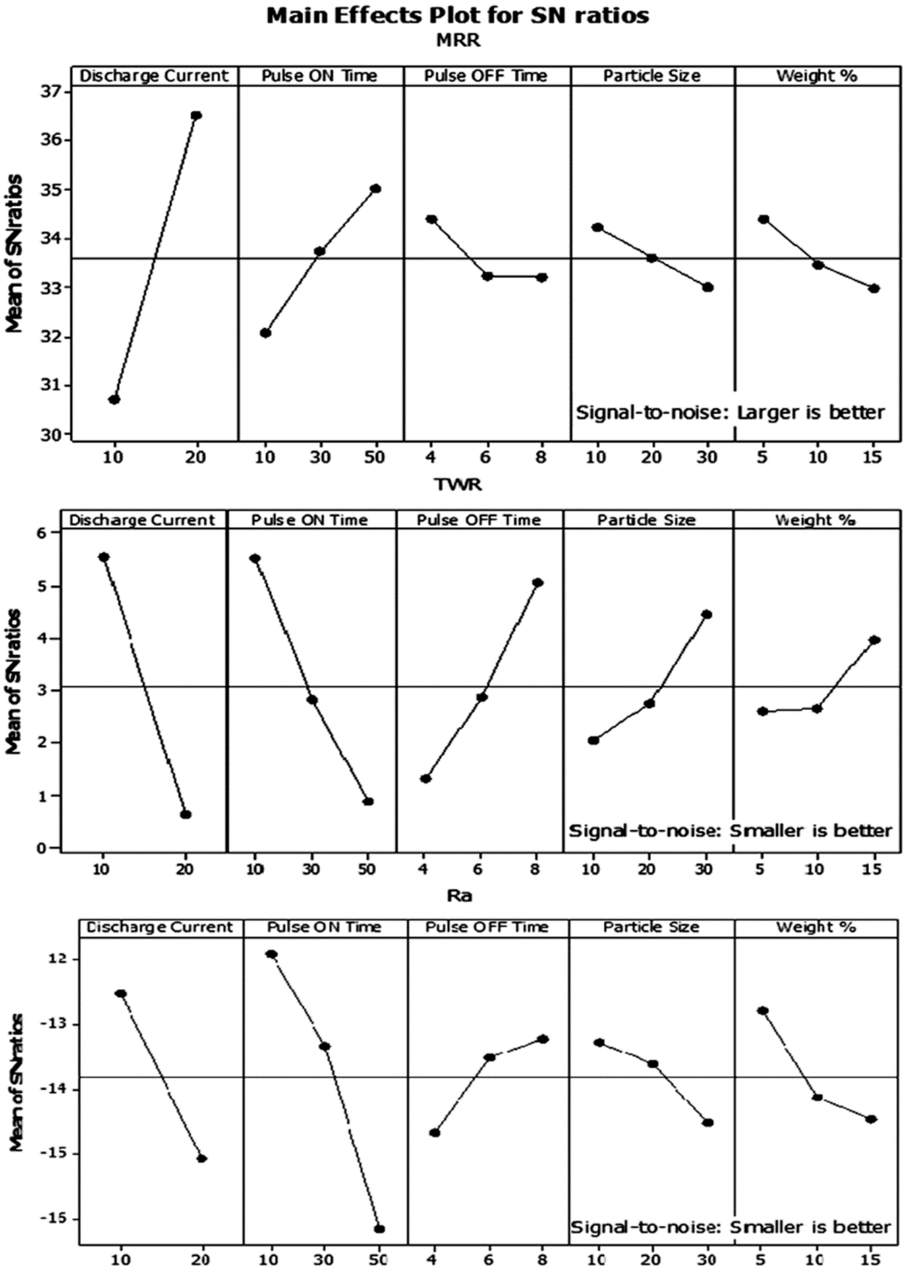

Fig. 3 — Effect of input parameters on MRR, TWR & surface roughness.

on time but decreases with increase in pulse off time, particle size and weight percentage of reinforcement. Increase in discharge current and pulse on time increases the spark energy and sparking time which results in increased MRR[9]. When the pulse off time increases the dwell time i.e. time without spark or time without material removal increases and hence the MRR decreases. The increase in reinforcement size and weight percentage decreases the MRR due to the non conducting nature of the reinforcements which affects the sparking during machining. The ceramic reinforcements in the composites don't melt during EDM and the matrix material around the reinforcements is melted, as a result the material removal in MMC occurs. The reinforcements act like a shield in front of matrix materials and reduce the material removal which results in reduced MRR[7].

Main effect plot for TWR given in Fig. 3 confirms that the TWR increases with increase in discharge current & pulse ON time and decreases with increase in other remaining parameters. Increased discharge current and sparking time leads to the loss of material in the tool. With increase in pulse off time, the sparking occurs with increased time interval i.e. the no of sparks per minute decreases and hence the TWR decreases. At higher reinforcement size and weight percentage the material removal at the work piece is decreases and concurrently the material removal at the tool end also decreases[8].

Generally, the surface of the materials specimen acquired after EDM compiles up with numerous microscopic craters interlinked with random spark discharge that originates between electrodes[22]. The energy of the discharge proves to be a decisive factor for crater size primarily formed over work specimen surface. A deeper cavity forms usually whenever more energetic pulses gets generated thereby directing for higher material removal. Amidst the reasons as and when the cavity depth increases, concurrently the roughness value also gets increased[9]. When the pulse off time is high the time for flushing removed debris is high and hence the clean surface will be exposed for the next spark to happen. On the other hand incomplete flushing leads to improper sparking and increased surface roughness. Increase in reinforcement size and weight percentage increases the surface roughness. Due to the high temperature produced at the time of sparking the matrix material around the reinforcemnt melts and the reingforcements are detached (leaves voids) or protrudes from the materials surfae which results in increased surface roughness[23,24].

Through regression analysis mathematical equations were developed for predicting the response variables (equation 5, 6 & 7). The developed regression equations for MRR, TWR and Ra is as follows

$$TWR = 0.342875 + 0.035288\ C + 0.006237\ N - 0.0345\ F - 0.002342\ S - 0.002583 \quad \ldots(5)$$

$$MRR = 4.46608 + 3.28004\ C + 0.318375\ N - 0.573833\ F - 0.240867\ S - 0.411533\ W \quad \ldots(6)$$

$$SR = 0.161972 + 0.166867\ C + 0.060142\ N - 0.188417\ F + 0.036183\ S + 0.08755\ W \quad \ldots(7)$$

Where C- Discharge Current, N- Pulse ON Time, F- Pulse OFF Time, S- Particle Size and W- Weight % of reinforcement.

3.2.2 Multi objective optimization

Multi objective optimization was done through Taguchi based GRA method. GRA and ANOVA were performed with the help of Minitab 16 statistical software. GRC and GRG with their rank for corresponding experimental run is calculated and given in Table 6. Variation of GRG values on each experimental run is plotted and given as Fig. 4. Mean GRG for each level of all the parameters considered is calculated so as to identify the optimum condition. The parameter level which has highest mean GRG is considered as the optimal level for that parameter. For example mean GRG for discharge current level 1 is calculated by taking the average of GRG values from exp. 1-9. Similarly for second level of discharge current the average of GRG values from exp 10-18 is calculated. By the same way, the mean GRG for each level of factors was calculated and are as illustrated in Table 7. Variation of mean GRG with respect to each process parameter and their level is shown in Fig. 5. Total mean value of the GRG is also calculated and given in Table 7.

Table 7 gives the average GRG at each level in which the optimum levels for each parameters considered were highlighted boldly. The difference between the maximum and minimum GRG values were calculated for each process parameters and the rank is given based on that. The parameter which has highest Max-Min value is ranked high and it is considered as highest influencing factor. From the Table 7, it can be noted that the parameters for highest GRG is discharge current (level 1), pulse ON time (level 1), pulse OFF time (level 3), Particle size (level 2) and Weight % (level L 3). It is noticeable

Table 6 — Grey relational coefficients and grey relational grade.

Trial No	Grey Relational Coefficient			Grey Relational Grade	Rank
	MRR (mm^3/min)	TWR (mm^3/min)	Ra (µm)		
1	0.403474	0.702867	1	0.702114	3
2	0.361625	0.863394	0.976581	0.733867	1
3	0.333333	1	0.803468	0.712267	2
4	0.40668	0.512999	0.717728	0.545802	16
5	0.375865	0.692044	0.730298	0.599403	8
6	0.403533	0.716563	0.787642	0.635913	5
7	0.464045	0.527036	0.646655	0.545912	15
8	0.422922	0.569317	0.568563	0.520267	17
9	0.431362	0.597048	0.687633	0.572014	12
10	0.606213	0.485886	0.603848	0.565316	13
11	0.681516	0.448199	0.974624	0.701447	4
12	0.641091	0.507847	0.700504	0.616481	6
13	0.764854	0.389504	0.486825	0.547061	14
14	0.726924	0.440872	0.571792	0.579863	11
15	0.749148	0.445239	0.578363	0.590917	9
16	0.810502	0.333333	0.333333	0.49239	18
17	1	0.377508	0.386418	0.587975	10
18	0.91783	0.390256	0.506156	0.604747	7

Table 7 — Average GRG at each level.

Process Parameter	Average GRG			Max-Min	Rank
	Level 1	Level 2	Level 3		
Discharge Current (A)	0.618618*	0.587355	-	0.031263	5
Pulse ON Time (µs)	0.6719*	0.58316	0.553884	0.118016	1
Pulse OFF Time (µs)	0.566432	0.62047	0.622056*	0.055624	2
Particle Size (µm)	0.6`16711*	0.607912	0.584336	0.032375	4
Weight %	0.628332*	0.583287	0.597339	0.045045	3

Total mean value of the grey relational grade = 0.602986
*optimal parameter level

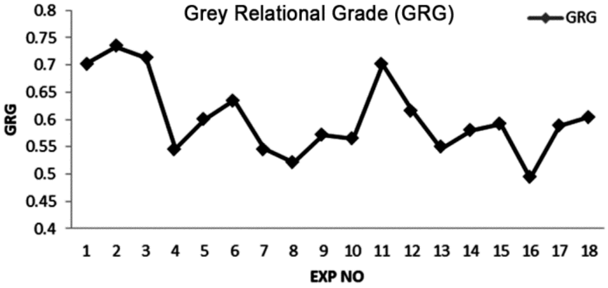

Fig. 4 — GRG for all experiments.

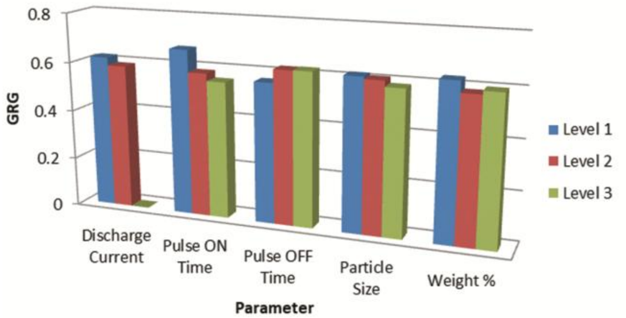

Fig. 5 — Variation of average GRG against input parameters.

that the optimal combination for highest GRG is C1N1F3S2W3. Figure 6 shows the main effect plot for SN ratio of GRG which also shows the same combination of process parameters for better GRG.

ANOVA is performed to identify the effect of each process parameters on multiple quality characteristics. The percentage contribution column showed in the Table 8 explicit the percentage effect of each factor over the GRG. The results reveal that POT influences the GRG by 55.36% which is highest among the considered parameters followed by pulse off time (14.70%), weight % of reinforcement (7.78%), Discharge current (5.37%) and particle size (4.11%).

3.3 Confirmation Test

Confirmation tests were performed to identify the accuracy of developed regression equations by comparing the response values obtained from the regression equation with experimental values. The predicted and experimental results obtained and the deviation between them (error percentage) is given in Table 9. The developed regression equations predict the response variables with minimal error.

P. TWR – Predicted TWR E. TWR – Experimental TWR

P. MRR – Predicted MRR E. MRR – Experimental MRR

P. Ra – Predicted surface roughness E. Ra – Experimental surface roughness

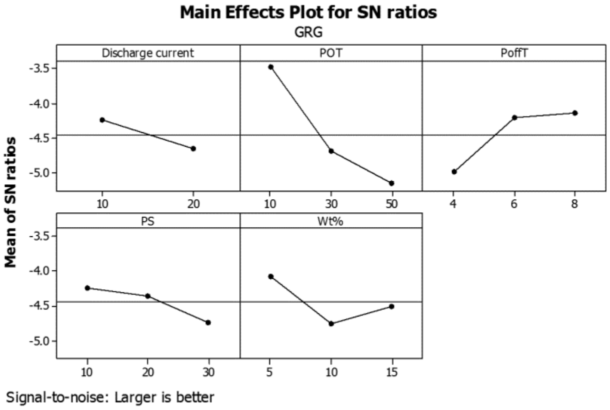

Fig. 6 — Effect of input parameters on GRG.

Where C- Discharge Current, N- Pulse ON Time, F- Pulse OFF Time, S- Particle Size and W- Weight % of reinforcement.

When the optimal level of process parameters were identified in GRA the final step is to predict and validate performance measure improvisations based on optimal level detected. A fortifiable intention for conducting confirmation experiment is mainly to authenticate the findings attained while analysis stage. The formula given in equation 8 helps in to calculate estimated γ_m via optimal levels decided for the process parameters:

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{n}(\hat{\gamma}_i - \gamma_m) \qquad \dots (8)$$

where γ_m is the total mean of the grey relational grade, $\hat{\gamma}_i$ is the mean of GRG at optimal level and n is the no of process parameters which notably influence the performance characteristics. Table 10 show cases the confirmation test results using the optimal levels of EDM process parameters. As illustrious from the Table, MRR decreases slightly from 35.589 to 35.103mm^3/min, while the TWR and Ra minimizes from 0.563 to 0.413mm^3/min and from 3.111 to 2.826μm, respectively. Furthermore a considerable

Table 8 — ANOVA results for GRG.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Discharge Current (A)	1	0.004398	0.004398	0.004398	3.39	0.103	5.37
Pulse ON Time (μs)	2	0.045332	0.045332	0.022666	17.46	0.001	55.36
Pulse OFF Time (μs)	2	0.012033	0.012033	0.006017	4.63	0.046	14.7
Particle Size (μm)	2	0.003363	0.003363	0.001681	1.29	0.326	4.11
Weight %	2	0.006374	0.006374	0.003187	2.45	0.148	7.78
Error	8	0.010388	0.010388	0.001298			
Total	17	0.081888					

Table 9 — Confirmation test for regression equations.

PROCESS PARAMETERS													
C	N	F	S	W	P. TWR	E.TWR	% ERROR	P. MRR	E. MRR	% ERROR	P. Ra	E. Ra	% ERROR
20	50	4	10	5	1.186	1.224	3.11	79.22	80.61	1.72	6.55	6.68	1.95
10	10	8	30	15	0.373	0.382	2.36	22.46	21.32	3.89	3.32	3.24	2.47
10	10	8	10	5	0.446	0.432	3.24	31.39	32.46	3.30	1.72	1.68	2.38

Table 10 — Results of performance measures for initial and optimal process parameters

	Initial machining parameters	Optimal machining parameters	
		Predicted	Experimental
Combination level	C1N1F1S1W1	C1N1F3S1W1	C1N1F3S1W1
MRR(mm^3/min)	35.589	-	35.103
TWR(mm^3/min)	0.563	-	0.413
Ra(μm)	3.111	-	2.826
GRG	0.70211	0.69097	0.7838

improvement of 0.0817 could be noted here in GRG after validation.

4 Conclusions

A novel aluminium rock dust composite is fabricated through stir casting and single and multi objective optimization for EDM and material parameters were done. From the analysis the following conclusions were drawn.

(i) Hardness of the composite increases with increase in reinforcement percentage and its size.

(ii) The optimal condition for better MRR is C2N3F1S1W1, for lesser TWR is C1N1F3S3W3 and for improved surface finish is C1N1F3S1W1. Rock dust % and its size affect the response parameters significantly.

(iii) The optimal condition for better MRR and lesser TWR & Ra is C1N1F3S1W1.

(iv) The usefulness of GRA was effectively verified by a mere comparison with that of confirmation experiments. This study revealed that the optimum parameter setting is directional for better MRR and reduced TWR & Ra in EDM process of aluminium rock dust composite than the initial parameter setting.

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