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Multi-objective optimization of the aluminum powder-mixed EDM process using the GRA and TOPSIS techniques based on the fuzzy AHP approach

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Abstract: Electric discharge machining is an advanced machining technique. Spark is initiated between the tool and work piece interface which has a gap between them. Low material removal rate as well as low surface finish is a major concern of this process. Therefore, powder-mixed electric discharge machining (PMEDM) is developed. In the PMEDM process, powders like silicon, aluminum, chromium, manganese, among others, are circulated along with dielectric fluid in a particular proportion. In this present study, aluminum powder is mixed in the dielectric fluid. The responses such as material removal rate, tool wear rate and surface roughness are measured by considering current, pulse on time and aluminum powder concentration as process parameters. The response surface methodology along with the fuzzy AHP TOPSIS and the grey relational analysis are used for optimization.

Keywords: PMEDM process, aluminum powder, response surface methodology, fuzzy AHP TOPSIS, GRA technique

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1. Introduction

Electric discharge machining is an advanced technique of machining. In this technique, there is a gap between tool and work piece and high energy pulse is passed between them. Due to high energy pulses, a spark is initiated and machining is carried out. There are multiple process parameters such as current, pulse on time, duty cycle, flushing pressure, among others. But current and pulse on time are the most influential parameters (Pradhan & Biswas, 2011; Singh & Pradhan, 2014). By this technique, complicated designs can be machined and its ability to machine hard materials irrespective of their properties makes this technique extremely important. It has many advantages but its low productivity is a major issue. To triumph over this issue, the powder-mixed EDM process came into existence (Kansal et al., 2007b).

In the powder-mixed EDM process, powders either metallic such as manganese, aluminum, among others, or non-metallic such as graphite, among others. of grain size below 100 microns are mixed in the dielectric fluid. In a study conducted by Tripathy and Tripathy (2016) proves that mixing of chromium powder in dielectric fluid improves the material removal rate, tool wear rate, electrode wear ratio and surface roughness. Tien-Long Banh et. al. (2018) conducted a study for the titanium powder-mixed EDM process. The results show that it has corresponding effect on material removal rate, tool wear rate and surface micro-hardness. A similar study has been conducted by Nguyen et al. (2018), titanium powder has been used to improvise the surface quality which include surface roughness, hardness, white layer thickness, crack formation and surface topography. Hosni et al. (2018) also conducted the experiments by mixing chromium powder in dielectric fluid. The mixing of chromium powder minimizes the recast layer. Kazi et al. (2021) has conducted a study by using silicon and chromium powder. The results show that there is corresponding improvement in material removal rate, tool wear rate. Kumar and Ahsan (2017) studied the effect of tungsten powder on the response variables in PMEDM. EN-31 steel has been selected as work piece material and copper is used as electrode. Addition of an optimum amount of powder in the dielectric fluid has an impact on the material removal rate positively and reduces the tool wear rate. Kansal et al. (2005) describes a study which mainly focuses on the optimization of the EDM process when silicon powder is suspended into the dielectric fluid of EDM. Response surface methodology is used for optimization. The machining parameters considered are peak current, pulse duration, duty cycle and concentration of silicon powder. The response variables are MRR and surface roughness. The obtained experimental results indicate significantly improved performance of PMEDM over EDM. There is another study conducted by Kansal et al. (2007a) which focuses on maximizing the MRR is studied by considering gain and nozzle flushing as process parameters along with previous process parameters. Kolahan and Bironro (2008) conducted experiments using aluminum powder and it is found that concentration and grain size of aluminum powder improves the material removal rate and electrode wear rate. Waghmare et al. (2019) conducted experiments on AISI D2 steel by mixing silicon and aluminum powder in the dielectric fluid. The responses considered for study are material removal rate, tool wear rate, surface roughness, surface crack density and white layer thickness. The results prove that mixing of silicon and aluminum powder has improved all the response variables. Reddy et al. (2014) studied the effect of metal powders such as aluminum (Al) and copper (Cu) mixed in the dielectric fluid, while machining of AISI D3 Steel and EN-31 steel. The output responses taken under consideration are material removal rate and surface's roughness. The results prove that the addition of metal powders in dielectric fluid improves the material removal rate and surface integrity. Panda and Kumar (2019) conducted the experiments by mixing manganese powder in dielectric fluid. XRD analysis is carried out and it is found that very less amount of manganese is deposited on the specimen's surface. This proves that the powder-mixed EDM process has low ill effects on the specimen's surface.

In this present study, the effect of aluminum powder mixed in dielectric fluid is studied. The responses considered are material removal rate, tool wear rate and surface's roughness. The experiments are designed based on response surface methodology. The optimization is carried out by GRA and TOPSIS technique based on the fuzzy AHP approach.

2. Materials and methods

In this present study, the aluminum powder-mixed EDM process is investigated for material removal rate, tool wear rate and surface roughness. Elektra Pulse PS50 ZNC machine by Electronica India Pvt. Ltd. is used to conduct the experiments. The machine has parameter selection with current up to 50A, pulse on time up to 2500 micro-sec and gap voltage up to 100V and the machine runs with both positive and negative polarity. The machining time for each experiment is fixed at 10 minutes. EDM oil used is synthetic EDM oil- IPOL SEO450.

2.1. Work-piece and tool selection

For this study, AISI D2 steel is used. AISI D2 steel is very hard material with hardness up to 60 HRc when hardened. It is wear and abrasion resistant and hence, it is used for dies, rollers, knives, among others. The material has 1.40-2.0% carbon, 11.0-21.0% chromium and other alloying elements like silicon, vanadium, manganese, among others. Copper is used as a tool with

10mm diameter. There are various other tool options such as graphite, copper tungsten, brass, among others. But copper has good electrical and thermal conductivity as compared to others and also it is a cheaper option than copper tungsten.

2.2. Powder selection

In this study, aluminum is used for study. The mixing of powder in the dielectric fluid improves the conductivity of fluid and hence increases the material removal rate. aluminum being very good conductor of electricity, it is used in this work. Aluminum has electrical resistivity of 2.45 μΩ.cm and thermal conductivity of 2.38 W/cm.K. It has a melting point of 660oC. The powder used has grain size of 40 microns and is mixed in the fluid with specific proportion.

2.3. Parameters selection

Trial experiments are conducted by considering current, pulse on time and gap voltage as input parameters to decide the levels and values of process parameters for final design. The parameters selected for the final experimentation are current, pulse on time and aluminum powder concentration. Certain parameters which are kept constant are- gap voltage - 50V, flushing pressure - 0.1kg/cm^2, Polarity - positive, and duty cycle - 50%. The design of experiments are as shown in Table 1.

Table 1. Design of experiments.

Process parameters	Level 1	Level 2	Level 3
Current(A)	6	8	10
Pulse on time(μs)	100	150	200
Aluminum powder conc. (g/l)	2	4	6

2.4. Response variable selection

Electric discharge machining has limitation of low material removal rate and surface finish. Hence, the response variables which are considered for study are material removal rate, tool wear rate and surface roughness. Material removal rate is measured by considering the weight of work piece before and after machining and also the time for which machining is done. The ratio of weight and time provides the material removal rate. Tool wear rate is also measured in the same way. The tool is measured before and after machining. Surface roughness is measured by surface roughness tester at three different points and by center line average method, surface roughness is calculated.

2.5. Methodology

In this present study, runs are designed based on response surface methodology technique. Response surface methodology provide design of experiments and also can be used for single objective optimization. In this technique, the responses are investigated for various combinations of input parameters and surface plots are generated. If the plots are flat in design or if the contours are linear in design, then the results are far from optimum value and hence to attain the optimum value, differential equation of first order is used. In this equation, all the terms are linear which provides coarser movement towards optimum condition. If the plots have a curvature, then the responses are near optimum condition and second order or quadratic differential equation is used which provides a fine movement (Khuri & Mukhopadhyay, 2010; Montgomery, 2017).

The runs are designed based on response surface methodology on MINITAB software. Total 20 experiments are needed to be conducted.

2.6. Optimization Techniques

In this present study, the results are optimized based on the grey relational analysis (GRA) and TOPSIS technique. The weightages for both the techniques are calculated using the fuzzy AHP approach.

2.6.1. Fuzzy AHP approach

The procedure to implement the fuzzy AHP approach (Gumus et al., 2013; Patil & Kant, 2014) is as follows:

Step 1 – Generation of pair-wise comparison matrix

In this step, the comparison of each response with respect to other responses is done. The matrix is generated by considering the criteria- 1=equal importance, 3=Moderate importance, 5=Strong importance and 7=Very strong importance and 2, 4, 6= Intermediate values.

Step 2 – Fuzzification of pair-wise comparison matrix

The Fuzzification is carried out by considering the relations: 1= (1, 1, 1), 2= (1, 2, 3), 3= (2, 3, 4), 4= (3, 4, 5), 5= (4, 5, 6), 6= (5, 6, 7), 7= (7, 7, 7). The inverse relation is given as, (X, Y, Z) = (1/Z, 1/Y, 1/X).

Step 3 – Calculate fuzzy geometric mean.

Fuzzy geometric mean is calculated by the following relation:

Fuzzy geometric mean = (X1*X2*X3, Y1*Y2*Y3, Z1*Z2*Z3)

Step 4 – Calculate fuzzy weights and crisp weights.

Fuzzy weights are calculated by following relation:

Fuzzy weights = (X1*Y1*Z1) [(X1+X2+X3+X4, Y1+Y2+Y3+Y4, Z1+Z2+Z3+Z4)-1]

The fuzzy weights are then converted to crisp weights by considering the relation in step 2. The sum of crisp weights must be equal to 1 and hence normalization is done. After this procedure is carried out, the weightage for each response variable is calculated which is fed as an input to the GRA and TOPSIS processes.

2.6.2. GRA technique

In this step, the weightages from the fuzzy AHP approach are used to implement the GRA technique (Kuo et al., 2008; Surekha et al., 2019). The procedure to implement GRA technique is as follows:

Step 1 – Normalize the data

The data or output responses need to be normalized i.e. converting them from 0 to 1. The conversion is done by following equations:

For maximizing criteria, i.e. for MRR

$$x_i * (k) = \frac{x_i(k) - min.x_i(k)}{max.x_i(k) - min.x_i(k)}$$

Step 2 – Calculate the grey relational coefficient.

To calculate the grey relational coefficient, deviation sequence have to be calculated. Deviation sequence is the difference between maximum value of $x_i^*(k)$ and the corresponding value of $x_i^*(k)$. The maximum value for all the responses is 1.00 as the data is normalized between 0 and 1.

Now to calculate the grey relational coefficient, the maximum value and minimum value of deviation sequence is noted. The maximum and minimum value of deviation sequence is 1 and 0 respectively. The grey relational coefficient is calculated by following equation:

$$GRC = \frac{\Delta_{\min} + \varepsilon.\Delta_{\max}}{\Delta_{oi}(k) + \varepsilon.\Delta_{\max}}$$

Where, $\Delta_{oi}(k)$ = Deviation sequence
ε = Deviation = 0.5

Step 3 – Calculate the grey relation grade and rank.

The grey relation grade is calculated by taking the average of the grey relational coefficient. Higher the value of the grey relational grade, lower is the rank.

2.6.3. TOPSIS technique

TOPSIS technique (Huu-Phan et al., 2020; Lai et al., 1994) is used to predict the optimum level of process parameters. The steps to implement TOPSIS technique is as follows:

Step 1 – Normalize the data and calculate weighted normalized matrix. In TOPSIS technique, the data is normalized by following relation:

$$\overline{X_{ij}} = X_{ij} / \left(\sqrt{\sum_{j=1}^{n} X_{ij}^2}\right)$$

Weighted normalized matrix is calculated by multiplying the normalized matrix by the weights which are calculated by the fuzzy AHP approach.

Step 2 – Ideal best and worst solution is determined. For maximizing criteria i.e. for MRR, ideal best solution is the maximum value of weighted normalized matrix while ideal worst solution is the minimum value of weighted normalized matrix. For minimizing criteria, the ideal best solution is minimum value of weighted normalized matrix and ideal worst solution is maximum value of weighted normalized matrix.

Step 3 – Distance from ideal best and ideal worst solution is determined. The distance from ideal best and ideal worst solution is determined by following relation:

$$S^+ = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^+\right)^2}$$

$$S^- = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^-\right)^2}$$

Step 4 – Determine preference value and rank.

The preference value is ratio of ideal worst solution to the sum of ideal best and ideal worst solution. Higher the value of preference value, lower is the rank.

Equations should be embedded using standard plug-ins like Mathtype or the Word Equation Editor contained in versions of Microsoft Word up to 2003 (or 2004 for the Macintosh) or the legacy equation editor in Word 2007, 2008 for Mac.

$$\Gamma_{R,S}(\tau) = \frac{(T_S^2 + T_R^2)\pi}{2} \exp\left(-\frac{\tau^2}{T_S^2 + T_R^2}\right) \tag{1}$$

3. Results and discussion

The results for all three response variables are as mentioned in Table 2.

3.1. Analysis of variance

The summarized analysis of variance for all three response variables are generated. Table 3 consist of p-value, f-value and significance of each response combined in a single table.

Current and pulse on time are the most significant parameters having significance of about 100%. Aluminum powder concentration has moderate significance of about 50% in case of material removal rate and surface roughness while the significance is about 97.6% in case of tool wear rate. The value of R-sq for all three response variables is above 80%, i.e., the process parameters considered are significant.

3.2. Main effect plots

Main effect plot are generated for all three process parameters. Three separate plots are generated for each of the response variables as shown in Figure 1(a), (b) and (c).

Table 2. Results for the aluminum powder-mixed EDM process.

Run #	I_p (A)	T_{on} (µs)	Al. Pd. Conc (g/l)	MRR (g/min)	TWR (g/min)	SR (µm)
1	6	200	2	0.05	0.0002	7.700
2	8	150	4	0.05	0.0003	8.679
3	8	150	4	0.06	0.0004	8.965
4	8	150	4	0.05	0.0004	9.003
5	8	150	4	0.03	0.0005	9.746
6	6	200	6	0.05	0.0005	8.061
7	8	200	4	0.07	0.0007	10.595
8	8	150	4	0.06	0.0005	8.843
9	10	100	2	0.05	0.0005	7.784
10	8	150	2	0.04	0.0003	9.898
11	6	150	4	0.04	0.0003	6.896
12	8	150	4	0.04	0.0006	9.199
13	8	150	6	0.05	0.0007	9.224
14	10	200	6	0.09	0.0008	10.03
15	10	200	2	0.09	0.0007	10.214
16	10	150	4	0.07	0.0006	10.253
17	10	100	6	0.06	0.0008	7.139
18	6	100	2	0.03	0.0001	8.188
19	6	100	6	0.03	0.0003	7.683
20	8	100	4	0.03	0.0002	7.979

Table 3. Analysis of variance for the aluminum powder-mixed EDM process.

Source	MRR			TWR			SR		
	F-Value	P-Value	Sig. %	F-Value	P-Value	Sig.%	F-Value	P-Value	Sig. %
Model	7.53	0.002	99.8	5.36	0.007	99.3	4.79	0.011	98.9
Linear	20.54	0.000	100	15.81	0.000	100	8.64	0.004	99.6
I_p	32.53	0.000	100	28.36	0.000	100	11.05	0.008	99.2
T_{on}	28.59	0.000	100	7.09	0.024	97.6	14.25	0.004	99.6
Al	0.51	0.492	50.8	11.98	0.006	99.4	0.63	0.446	55.4
Square	1.46	0.283	71.7	0.19	0.899	10.1	2.65	0.106	89.4
I_p*I_p	2.09	0.179	82.1	0.00	0.951	4.9	4.46	0.061	93.9
T_{on}*T_{on}	0.26	0.621	37.9	0.00	0.951	4.9	0.1	0.762	23.8
Al*Al	0.18	0.680	32.0	0.40	0.540	46.0	0.15	0.710	29.0
Interaction	0.58	0.640	36.0	0.09	0.965	3.5	3.07	0.077	92.3
I_p*T_{on}	1.43	0.259	74.1	0.09	0.772	22.8	8.57	0.015	98.5
I_p*Al	0.16	0.699	30.1	0.09	0.772	22.8	0.14	0.720	28.0
T_{on}*Al	0.16	0.699	30.1	0.09	0.772	22.8	0.51	0.491	50.9
Lack-of-Fit	0.15	0.97		1.56	0.318		5.20	0.047	

From the main effect plot for MRR, MRR increases at a current of 10A, pulse on time of 200µs and aluminum powder concentration of 6g/l.

The TWR is minimum at a current of 6A, pulse on time of 100µs and aluminum powder concentration of 2g/l while Surface roughness is minimum at a current of 6A, pulse on time of 100µs and aluminum powder concentration of 6g/l.

From the results, it is clear that the value of the process parameters is different for each of the process parameters. Hence, a multi-objective optimization is needed to be done.

The multi-objective optimization is carried out by two techniques- the grey relational analysis and the TOPSIS approach. The weights for both the techniques are calculated based on the fuzzy AHP approach.

3.3. Application of the fuzzy AHP approach

The weightages are calculated based on the procedure mentioned in Section 2.6.1. The results generated based on this approach is as follows:

Step 1 – Generation of pair-wise comparison matrix

Based on these criteria, pair wise comparison matrix is generated as shown in Table 4.

Table 4. Pairwise comparison matrix.

	MRR	TWR	SR
MRR	1	3	1/5
TWR	1/3	1	1/6
SR	5	6	1

The criteria is designed based on the decision that importance of the responses in the following chronology: Surface roughness>MRR>TWR.

Step 2 – Fuzzification of pair-wise comparison matrix. The fuzzified matrix is as shown in Table 5.

Table 5. Fuzzified comparison matrix.

	MRR	TWR	SR
MRR	(1, 1, 1)	(2, 3, 4)	(1/6, 1/5, 1/4)
TWR	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/7, 1/6, 1/5)
SR	(4, 5, 6)	(5, 6, 7)	(1, 1, 1)

Step 3 – Calculate fuzzy geometric mean

The fuzzy geometric mean calculated for each of the responses is mentioned in Table 6.

Step 4 – Calculate fuzzy weights and crisp weight. The value of fuzzy weights and crisp weights are mentioned in Table 7.

From Table 7, weightage for MRR is 23.8%, TWR is 13.4% and Surface roughness is 62.8%. The crisp weights are fed as an input to GRA and TOPSIS optimization problems.

Table 6. Fuzzy geometric mean.

	MRR	TWR	SR	Fuzzy geometric mean
MRR	(1, 1, 1)	(2, 3, 4)	(1/6, 1/5, 1/4)	(0.760, 0.880, 1.000)
TWR	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/7, 1/6, 1/5)	(0.435, 0.485, 0.562)
SR	(4, 5, 6)	(5, 6, 7)	(1, 1, 1)	(2.115, 2.340, 2.546)

Table 7. Fuzzy weights and crisp weights.

Fuzzy geometric mean	Fuzzy weights	Crisp weights
(0.760, 0.880, 1.000)	(0.185, 0.238, 0.302)	0.238
(0.435, 0.485, 0.562)	(0.106, 0.131, 0.170)	0.134
(2.115, 2.340, 2.546)	(0.515, 0.632, 0.769)	0.628

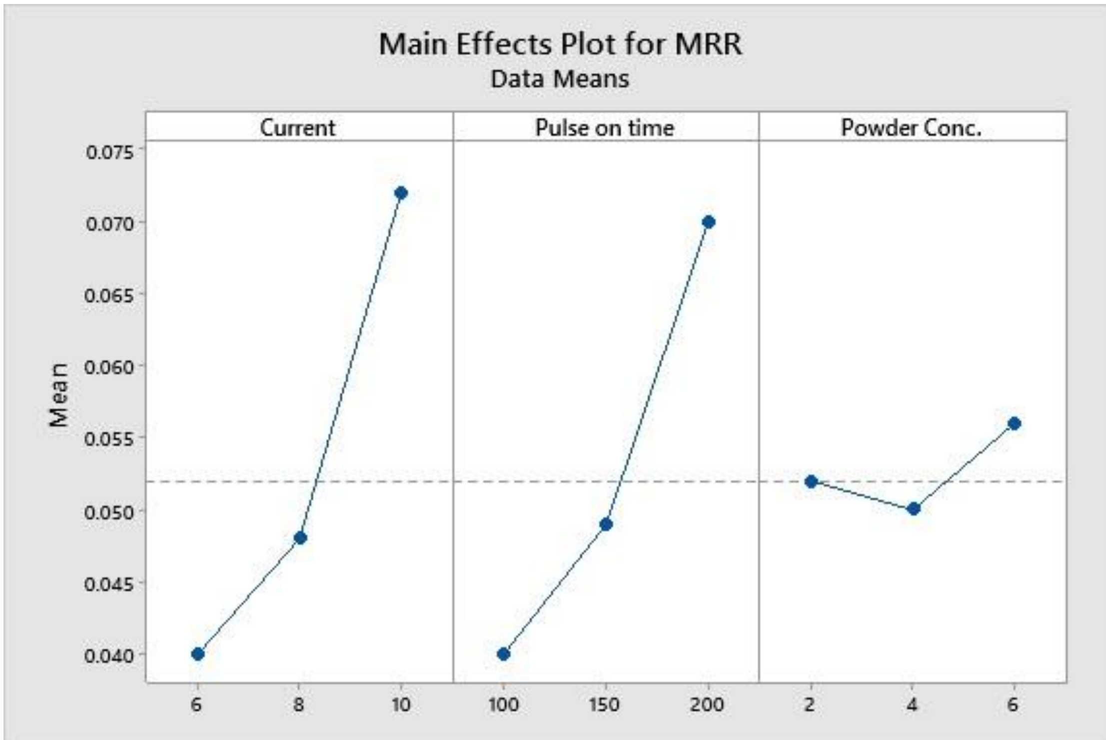
3.4. Application of the GRA technique

The GRA technique is implemented based on the procedure mentioned in Section 2.6.2. The grey relational coefficient, the grey relational grade and rank are mentioned in Table 8.

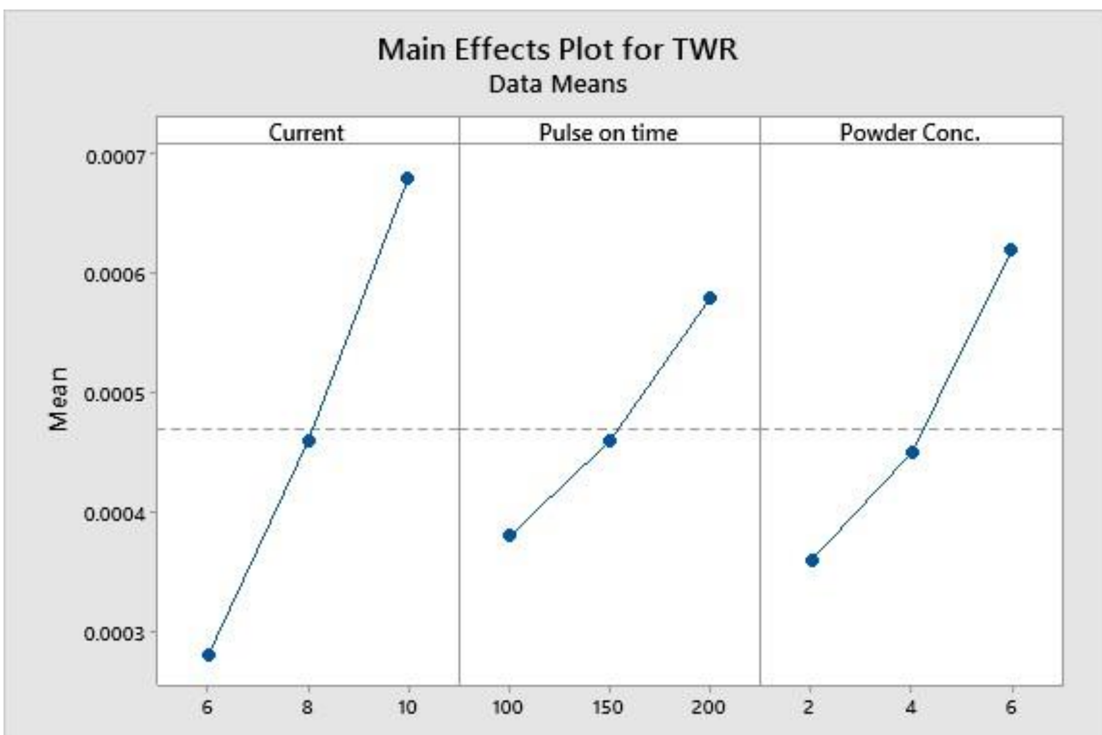
Table 8. The grey relation analysis.

Run order	MRR	TWR	Surface roughness	GRG	Rank
1	0.151	0.319	0.591	0.354	6
2	0.151	0.190	0.394	0.245	11
3	0.192	0.135	0.360	0.229	12
4	0.151	0.135	0.355	0.214	14
5	0.106	0.105	0.290	0.167	20
6	0.151	0.105	0.499	0.252	10
7	0.263	0.072	0.239	0.192	17
8	0.192	0.105	0.374	0.224	13
9	0.151	0.105	0.567	0.274	9
10	0.125	0.190	0.279	0.198	16
11	0.125	0.190	1.000	0.438	4
12	0.125	0.086	0.335	0.182	19
13	0.151	0.072	0.333	0.186	18
14	1.000	0.063	0.270	0.444	2
15	1.000	0.072	0.259	0.444	3
16	0.263	0.086	0.257	0.202	15
17	0.192	0.063	0.827	0.361	5
18	**0.106**	**1.000**	**0.473**	**0.527**	**1**
19	0.106	0.190	0.596	0.297	8
20	0.106	0.319	0.517	0.314	7

From the Table, run no. 18 is the optimum condition. The optimum values for the current is 6A, for the pulse on time is 100µs and for aluminum powder concentration is 2g/l.


Main Effects Plot for MRR
Data Means
Current
Pulse on time
Powder Conc.
Mean
0.075
0.070
0.065
0.060
0.055
0.050
0.045
0.040
6
8
10
100
150
200
2
4
6

(a)


Main Effects Plot for TWR
Data Means
Current
Pulse on time
Powder Conc.
Mean
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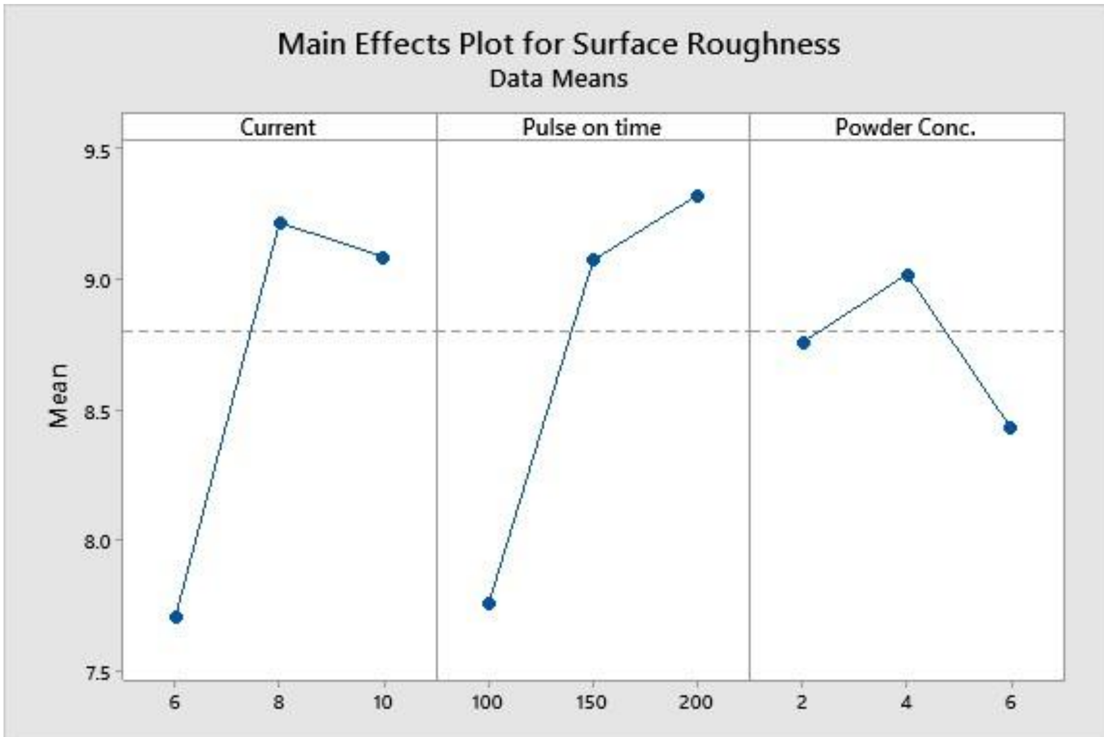
0.0006
0.0005
0.0004
0.0003
6
8
10
100
150
200
2
4
6

(b)



(c)

Figure 1. Main effect plot for: (a) MRR, (b) TWR, (C) surface roughness.

The confirmation test is conducted and the results generated are mentioned in Table 9.

Table 9. Confirmatory test results for the GRA technique.

	Optimum condition	Confirmation results	Error %
MRR (g/min)	0.03	0.04	33.33
TWR (g/min)	0.0001	0.0001	0.00
Surface roughness (µm)	8.188	8.574	4.714

From the confirmation results, it is clear that the optimum condition of the process parameters is a current of 6A, a pulse on time of 100µs and an aluminum powder concentration of 2g/l.

3.5. Application of the TOPSIS technique

The TOPSIS technique is implemented based on the procedure mentioned in Section 2.6.3. The optimized results from TOPSIS technique is mentioned in Table 10.

From the Table, run no. 1 is the optimum condition. The optimum values for the current is 6A, for the pulse on time is 200µs and for aluminum powder concentration is 2g/l.

The confirmation test is conducted and the results generated are mentioned in Table 11.

From the confirmation results, it is clear that the optimum condition of the process parameters is a current of 6A, a pulse on time of 200µs and an aluminum powder concentration of 2g/l.

Table 10. TOPSIS optimization table.

Run order	Si+	Si-	Preference value	Rank
1	0.041238	0.060865	1.536802	1
2	0.049385	0.046341	0.984709	8
3	0.047196	0.045355	1.006365	6
4	0.054087	0.03945	0.768826	14
5	0.077258	0.022063	0.307635	20
6	0.048874	0.047908	1.028151	5
7	0.07097	0.03922	0.591843	16
8	0.048395	0.043853	0.950003	12
9	0.047389	0.051645	1.141451	4
10	0.068925	0.032636	0.506135	17
11	0.049862	0.06619	1.393665	2
12	0.067321	0.026824	0.42528	19
13	0.063942	0.029704	0.494246	18
14	0.064281	0.058862	0.974551	9
15	0.063158	0.058779	0.989442	7
16	0.063693	0.040859	0.682357	15
17	0.05025	0.062027	1.296397	3
18	0.061676	0.055856	0.961489	10
19	0.06063	0.054587	0.954925	11
20	0.060936	0.054242	0.94439	13

Table 11. Confirmatory test results for TOPSIS technique.

	Optimum condition	Confirmation results	Error %
MRR (g/min)	0.05	0.06	20.00
TWR (g/min)	0.0002	0.0002	0.00
Surface roughness (μm)	7.700	8.128	4.714

4. Conclusions

From the analysis of variance, it can be concluded that current and pulse on time are the process parameters which have high influence on response variables MRR, TWR and surface roughness. Aluminum powder concentration has moderate significance on MRR and surface roughness, while it has high significance on TWR.

From the main effect plot, it can be concluded that MRR is high for a high value of current, but for a low value of TWR and surface roughness, the current must be low. For lower value of pulse on time, low TWR and surface roughness can be attained while higher pulse on time has higher value of MRR. In case of aluminum powder concentration, aluminum powder concentration of 6g/l provides high MRR and low surface roughness but aluminum powder concentration of 2g/l provides low TWR.

The weights are calculated by the fuzzy AHP approach. Surface roughness is considered more important in this case, hence the weightages calculated for MRR, TWR and surface roughness is 0.238, 0.134 and 0.628. The calculated weights are provided as an input for the GRA and TOPSIS techniques. The results are optimized by the GRA and TOPSIS approaches.

The optimum value for the GRA technique is a current of 6A, a pulse on time of 100μs and an aluminum powder concentration of 2g/l which is run no. 18. The optimum value for the TOPSIS technique is a current of 6A, a pulse on time of 200μs and an aluminum powder concentration of 2g/l which is run no. 1. The confirmatory results for both, GRA and TOPSIS, confirm the optimum value with small amount of error.

Comparing both optimization techniques, it can be concluded that a current of 6A and an aluminum powder concentration of 2g/l are common to both techniques, while there are complete opposite results for pulse on time.

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