Performance Study of EDM Process Parameters using TiC / ZrSiO4 Particulates Reinforced Copper Composite Electrode

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ABSTRACT

Electrical discharge machine (EDM) is widely employed in machining of components containing complex profiles those made up of hard-to-cut and machining materials. However, fabrication of tool time for EDM process consumes excessively high in traditional machining method which affects machining rate significantly. Therefore, in this current exertion, powder metallurgy (PM) technique is employed to fabricate the tool electrode using the materials such as copper (Cu), Titanium carbide (TiC) and zirconium silicate ($ZrSiO_4$) for different combinations. L 18 orthogonal array (OA) is planned using input parameters such as three types of tools (Cu, Cu_{90}, Cu_{80}), peak current (PC), pulse on time (PT) and gap voltage (GV). The performance of EDM is evaluated through material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR). The process parameters are optimized using two different techniques such as Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Grey Relational Analysis (GRA). TOPSIS and GRA optimization techniques produce the same optimal parametric solution for less TWR, SR and higher MRR with the combination of Cu_{90} tool, E8 Amp PC, 15 µs pulse µs PT and 75 V GV. Based on the ANOVA table of TOPSIS, pulse on time plays a major role which contributes around 46.8 % on the machining performance and peak current shows the most significant contribution around 39.3 % on machining performance using GRA values. Furthermore, the scanning electron microscope (SEM) image analyses are carried out on the machined work piece surface to understand the effect of tools on machining quality.

Keywords: Powder metallurgy, composite tool, Copper, EDM, TOPSIS, GRA

INTRODUCTION

EDM is widely accepted and promising process used in non-traditional machining process. Due to unique nature of machining characteristics, the usage of EDM has been increasing enormously day by day in manufacturing sectors such as forging, automobile, aviation, biomedical and medical industries. Moreover, an excellent surface finish and precision can be made by means of EDM where the conventional machining method fails. The Stainless steel (SS)-304 has been employed in various manufacturing sectors due to its high toughness, wear resistance and corrosion resistance feature. In EDM process, apart from electrical parameters, there are other parameters such as tool modification, dielectric medium changes, tool rotational assistances and tool vibration are playing vital role to improve machining performances. Therefore, various research attempts were endowed in last decade by the researchers world-wide. In line up with that, Sivakumar et al. [1] investigated the EDM process parameters for oil-hardening, non-deforming tool steel (OHNS) using copper and titanium die boride composite electrodes. They developed the electrode using powder metallurgy process and optimized the process through response surface methodology. Chakmakchi et al. [2] used the titanium alloy (Ti) as electrode for machining the cobalt-chromium (Co-Cr) alloy and Ti6Al7Nb through EDM process. The EDM process parameters were analyzed by the evaluations of morphological and electrochemical changes in the work piece and the results were validated with copper electrodes. They identified that Ti electrodes have less degradation effect on work-piece than copper electrode. Yadav et al. [3] used the geometry modified electrodes such as slotted, helical and tubular in EDM process. The influences of process parameters on the EDM performance were studied with the electrodes. They noted that removal of machined products from the inter electrode gap (IEG) with respect to all tools had increased the machining rate and surface roughness of work materials. Taherkhani et al. [4] investigated the EDM process parameters using Al2O3 particles mixed dielectric in various concentration ranges on titanium alloy. The significant enhancement in machining surface was due to the prevention of oxides lever formation in the dielectric medium. Also, the presence of oxygen and carbon elements leads to the uniform power distributions which control crack formations over the machining surface.

Phan et al. [5] tried the aluminum electrode in EDM process to find its suitability on the titanium alloy. They optimized the process parameters using Taguchi method and obtained the maximum MRR 0.0239 gm/min with less error. Ilani et al. [6 &7] fabricated tool in the technique of fused deposition modeling and employed in EDM to improve the machining performance. The result of this tool using the surfactant stirred dielectrics such as with powder mixed and non-powder mixed electrolyte. They noted 77 % improvement in surface roughness with this novel electrode. Also, this type of electrode is cost effective and makes the

EDM functions easier for the production of complex geometries. Phan et al. [8] coated aluminum- chromium- nickel on aluminum electrode to investigate the EDM parameters for titanium alloy. The experiments' results of coated electrode are compared with the non-coated aluminum electrode. The coating of aluminum in electrode increases the material removal rate significantly and coated electrode produces 24 % lesser TWR than uncoated electrode. Shaikh et al. [9] conducted the experiments with electrodes such as silver coated tungsten and electroless nickel coated electrode in EDM process. They noted that electroless nickel coated electrode is 20 % higher machining rate than silver coated tool. It is due to the fact that electroless nickel coating increases the current distributions on the electrode. Walia et al. [10] studied the influences of copper and titanium carbide mixed composite electrode on EDM with EN31 die steel. The copper composite electrode result reveals that roundness of hole reduced around 25 % due to the electrodes conductance change. They mentioned that significant performance results in terms of MRR and surface roughness were obtained with composite electrode than plain copper electrode. Sahu et al. [11] prepared the aluminum, silicon and magnesium mixed composite electrode through selective laser sintering method. They considered the titanium as work piece and conducted the experiments using various tools such as composite, graphite and copper electrodes. They obtained the higher TWR and excellent surface roughness on composite electrode than other tools. Mahipal Reddy et al. [12] employed the 3D printing method such as direct metal laser sintering to fabricate the aluminum composite electrode which used in the EDM of steel alloy. The experiment results were compared with the commercial electrodes and performances were evaluatedby means of MRR, TWR and SR. Vineet et al. [13] used the rotary type tool in EDM of work material such as high speed steel through air mixed glycerin dielectric medium. The tool rotation speed, gas pressure, current and dielectric flow rate were considered for the process parameters on the study of machining rate, overcut and surface roughness. They noted the notable improvement on machining rate and surface roughness with the rotary tool electrode. Padhi et al. [14] tried the additive manufacturing tool to machining the D2 Steel using EDM. They have coated the electrode with acrylonitrile based polymer by fusion deposition method which increased electrical conductance of electrode and increased the machining rate significantly. Mathai et al. [15] adopted the planetary tool movement on EDM to investigate the process parameters for titanium alloy. Along with this planter movement, they fabricated the square holes with two types of electrodes materials such as copper and graphite. Also, they mentioned that copper tool produced better machining rate and surface finish than the graphite electrodes. Wang et al. [16] tried the two types of electrodes such as cylindrical and helical in micro EDM process on titanium alloy. The helical electrode increases the debris removal passage between tool and electrode which increases the current flow ability. This phenomenon ensures the high machining rate and better surface finish on the micro holes. Vincentet al. [17] used the rotary electrodes such as copper and brass with EDM on En41b steel. They have noted that less tool wear rate on copper electrode than brass electrode due to the current fluctuation on the IEG. Also, bases on the analyses of variance pulse on time and pulse off time played major role on the machining performance. Singh et al. [18] investigated the EDM performance using air associated rotary tool on high chromium die steel. They compared the experimental results with non-air assisted EDM under same parameter setup. According to this, high machining rate and less overcut found on air assisted tool than the normal tool. Along with mixed dielectric and modified tool electrodes, the process parameters of EDM are optimized using various techniques such as TOPSIS, Taguchi-Data Envelopment Analysis based Ranking, Taguchi–grey relational analysis by the researchers [19-22]. The aforementioned literature clearly indicates that the various research methodologies have been followed by the researchers to enhance the EDM process. However research on powder metallurgy based tool on EDM process has become sparse. Although few literatures considered PM tools in EDM, all those methods show with poor surface finish and machining rate due to the improper reinforcements with Cu [23-25].Titanium carbide and zirconium silicate particles possessan excellent affinity with Cu material due to crystallographic nature [26]. Hence in this research two electrodes in different reinforcement combinations such as 90 % Cu, 5% TiC 5 % $ZrSiO_4$(Cu_{90}) and 80 % Cu, 5% TiC 5 % $ZrSiO_4$(Cu_{80}) are prepared using PM technique. The results of these tools are compared with plain Cu electrode. With these three tools, EDM and its process parameters are optimized using TOPSIS and GRA method. Furthermore, SEM image analyses are carried out for the better understanding of effect of PM based tools on machining performances.

EXPERIMENTAL SETUP

The experiments are conducted using ZNC EDM machine which is displayed in figure 1. The tool electrode prepared based on the powder metallurgy technique and hot extrusion method employed to diminish the porosity of composite. The materials such as Cu- TiC- ZrSiO4 are used for the tool electrode preparation with various weight ratios as shown in table 1. The procedures for producing tool electrode are followed from the literature [27] and explored in the figure 2. The grain sizes of reinforcement particles are considered as lower than 75 µm for all electrode samples. The composite electrode of diameter 10 mm and 5 cm length is prepared for the electrodes. With considering various application of stainless steel (SS), in this attempt 5 mm thick SS 304 materials are used as work material. The machining parameters levels and experimental planning with outcomes are shown in table 2 & 3. L 18 A is planned with four tool electrodes, PC, PT, and GV. The scanning electron microscope (SEM) pictures of PM based electrodes such as Cu, Cu $_{90}$, and Cu_{80} electrodes are shown in figure 3 to 5. The performances of EDM are estimated in terms of MRR, TWR and SR. The commercially available dielectric medium kerosene is used for flushing between the tool and electrode. The machining time is fixed as 30 Minutes for all experiments and levels of parameters are selected based on the literature [27]. Every completion of experiment work piece and electrodes are cleaned using acetone to remove debris from the machining zone of work piece. Before and after machining weights of tool and work piece are taken into the account for calculating the MRR and TWR respectively. The surface roughness of machined area is measured using surface roughness testing machine (Surf test SJ-210, Mitutoyo, Japan). Furthermore, SEM image analysis is carried out on the machined work piece surfaces for the better understanding of effect of tool on machining

Table 1.Weight ratios of electrode

Electrodes type	Electrodes No	% of Reinforcements

		Cu	TiC	$ZrSiO_4$
Cu	Cu	100	-	-
Cu_{90}	$Cu_{90}(TiC)_5(ZrSiO_4)_5$	90	5	5
Cu_{80}	$Cu_{80}(TiC)_{10}(ZrSiO4)_{10}$	80	10	10

Table 2. Range of Machining parameters

Symbol	Machining Parameters	Unit	L -1	L-2	L- 3
A	Electrode type	-	Cu	Cu_{90}	Cu_{80}
B	Peak Current	Amp	8	16	24
C	Pulse On	µs	15	30	45
D	Gap Voltage	V	50	75	100

Figure 1. EDM Setup

Figure 2. Powder metallurgy based electrodes

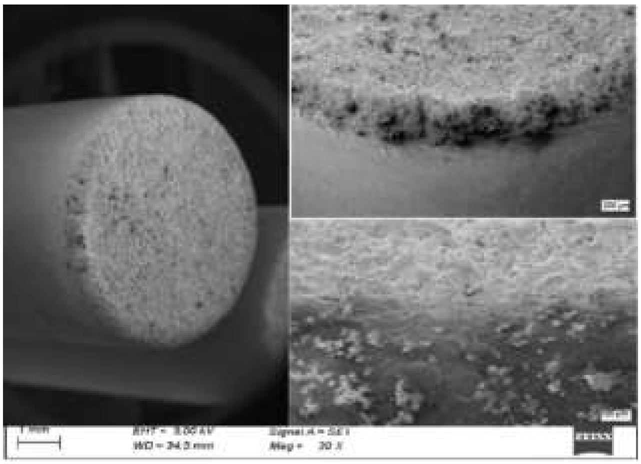

Figure 3. PlainCu electrode (Cu)

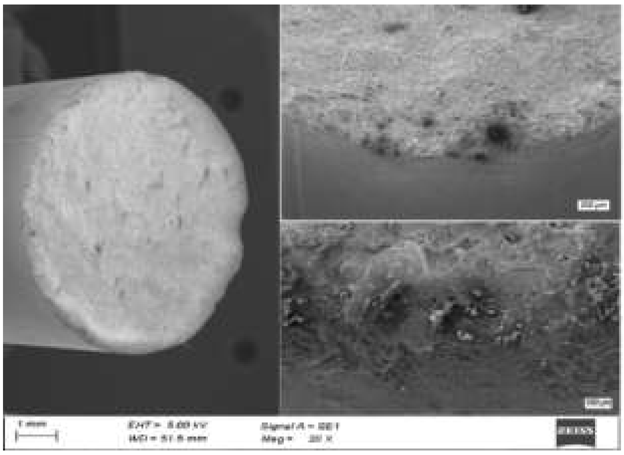

Figure 4. Cu_{90} TiC_5 $ZrSiO_5$ electrode (Cu $_{90}$)

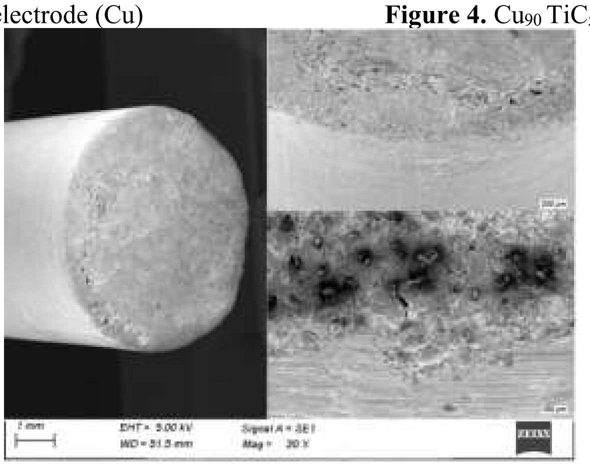

Figure 5. $Cu_{80}TiC_{10}ZrSiO4_{10}$ electrode (Cu $_{80}$)

Table 3. Experimental planning

Run	TE	PC	PT	GV	MRR in g/min	TWR in g/min	SR in µm
1	1	8	15	50	0.0101	0.0533	4.12
2	1	16	30	75	0.0011	0.0253	4.39
3	1	24	45	100	0.0231	0.0538	5.27
4	2	8	15	75	0.0365	0.0451	5.89
5	2	16	30	100	0.0112	0.0423	6.92
6	2	24	45	50	0.0099	0.0266	5.87
7	3	8	30	50	0.0098	0.0451	5.94
8	3	16	45	75	0.0012	0.0296	6.12
9	3	24	15	100	0.0014	0.0091	7.14
10	1	8	45	100	0.0356	0.0478	7.82
11	1	16	15	50	0.0085	0.0225	7.18
12	1	24	30	75	0.0130	0.0489	8.23
13	2	8	30	100	0.0201	0.0589	7.87
14	2	16	45	50	0.0173	0.0149	8.12
15	2	24	15	75	0.0194	0.0412	8.94
16	3	8	45	75	0.0080	0.0072	8.15
17	3	16	15	100	0.0251	0.0188	7.25
18	3	24	30	50	0.0097	0.0419	8.92

Multi objective optimization

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is one of the right techniques to identify the suitable parametric solution from the setoff experimental combinations. The procedures followed in this method are provided below [28, 29].
Step 1: Choice matrix included with "n" attributes and "m" alternatives which is shown with the equation 1.

$$E_m=\begin{bmatrix} R_{11} & R_{12} & R_{13} & \dots & \dots & R_{1n} \\ R_{21} & R_{22} & R_{23} & \dots & \dots & R_{2n} \\ R_{31} & R_{32} & R_{33} & \dots & \dots & R_{3n} \\ \vdots & \vdots & \vdots & \ddots & \ddots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \ddots & \vdots \\ R_{m1} & R_{m2} & R_{m3} & \dots & \dots & R_{mn} \end{bmatrix} \quad - (1)$$

Where Rij is the presentation of *i*th alternative with respect to *j*th attribute.

Step 2: The normalization of matrix values is carried out by equation 2.

$$r_{ij} = \frac{R_{ij}}{\sqrt{\sum_{i=1}^{m} R_{ij}^2}} \qquad j = 1,2,\dots,n. \qquad - (2)$$

Step 3: Weights for the output responses are assigned using equation 3 as W_j(j=1,2,….,n).

$$Y = W_j r_{ij} \qquad - (3)$$

where, $\sum_{j=1}^{n} W j = 1$

Step4: Suitable ideal result is estimated using equation 4 and worst ideal result is attained through equation 5.

$$Y^+ = \{(\sum_i^{max} Y\ ij\ |j \in J), \{(\sum_i^{min} |j \in J|\ i = 1,2,.m)\} \quad - (4)$$
$$= \{y_1^+, y_2^+, y_3^+, \dots \dots \dots, y_n^+\}$$
$$Y^- = \{(\sum_i^{min} Y\ ij\ |j \in J), \{(\sum_i^{max} |j \in J|\ i = 1,2,.m)\} \quad - (5)$$
$$= \{y_1^-, y_2^-, y_3^-, \dots \dots \dots y_n^-\}$$

Step 5: The value differences among the parameters are evaluated with the 'ideal' solution is presented in equation 6.

$$t_i^+ = \sqrt{\sum_{j=1}^{n} (Yij - y_j^+)^2}, \qquad i=1,2\dots m \qquad - (6)$$

The deviation of experimental results from the "worst –ideal" solution is represented in equation 7.

$$t_i^- = \sqrt{\sum_{j=1}^{n} (Yij - y_j^-)^2}, \quad i=1,2\dots m \qquad - (7)$$

Step 6: To find the closeness of various parameters solution, equation8 is employed which is presented below.

$$P_i = \frac{t_i^-}{t_i^+ + t_i^-} \qquad i=1,2,\dots m \qquad - (8)$$

Step 7: Obtained preference values (Pi) are ordered in downward manner to identify the best parameters solution.

Grey relational analysis technique (GRA)

In GRA method, output responses of different units should be converted into the homogeneous form i.e. unit less number. Therefore the experimental results are converted from zero to one through the below mentioned equations [28, 29]. The output values such as MRR, TWR and SR values are estimated using equations 9 and 10 respectively.

$$Y_i^*(P) = \frac{y_i(P) - \text{Min } y_i(P)}{\text{Max } y_i(P) - \text{Min } y_i(P)} \qquad - (9)$$

Where $i=1, 2, \dots m, \quad P = 1, 2, \dots n$

$$y_i^*(P) = \frac{\text{Max } y_i(P) - y(P)}{\text{Max } y_i(P) - \text{Min } y_i(P)} \quad - (10)$$

Where i=1, 2,…m, P = 1, 2,…n

Here, the equation contains 'm' means total number of experiments and 'n' means received data.

Equation 11is employed to estimate the gray relational coefficient (GRC) with the normalized values.

$$k_i(N) = \frac{\Delta_{Min} + \zeta\Delta_{Max}}{\Delta_{oi}(Q) + \zeta\Delta_{Max}} \quad - (11)$$

Here,Δ_{oi} (Q)divergenceseries is chosen from the reference sequence $k(N)$ and comparability sequence $k_i^*(N)$.The range 0 to 1 has been used for the distinguished coefficientki .

$$T_i = \frac{1}{n}\sum_{P=1}^{n} j_i(N) \quad - (12)$$

The weight value of each output responses are summation with GRC to find the gray relational grade (GRG)Ti is displayed in the equation 12.

RESULT AND DISCUSSION

Influences of Input parameters on MRR:

The influences of input parameters such as electrode, peak current, pulse on time and gap voltage on MRR are presented in figure 6. The experiments are conducted using three different tools which are displayed in table 3. The graphs are drawn according to the mean values of MRR against the input parameter values. It is clear from the figure that using of composite tools exhibit the higher MRR when compared to plain copper tool. Since, the PM based composite tools possess the uneven surface nature at the end face tool with porosity. Hence the passing of electric current gets fast movement between inter electrode gap which ensures higher MRR with composite electrode [30]. Also, MRR is increased with increasing percentage of titanium carbide and zirconium silicate in the composite tools. The softness of composite tool is increased by the presence of zirconium silicate which leads to high inter metallic gap among the particles. This phenomenon leads to better current conductance in the tool electrode and leads to the higher MRR. Moreover, from the figure, it is observed that increasing of peak current increases the MRR. It is a common fact that when increasing of current with no flow disturbance in the electrode can produce the narrow power supply in the machining zone which causes higher MRR [31]. The same trend of higher MRR has been obtained with increasing of pulse on time and gap voltage. Since the timing of current passage and flow ability increases at higher level which leads to the higher MRR for all tools.

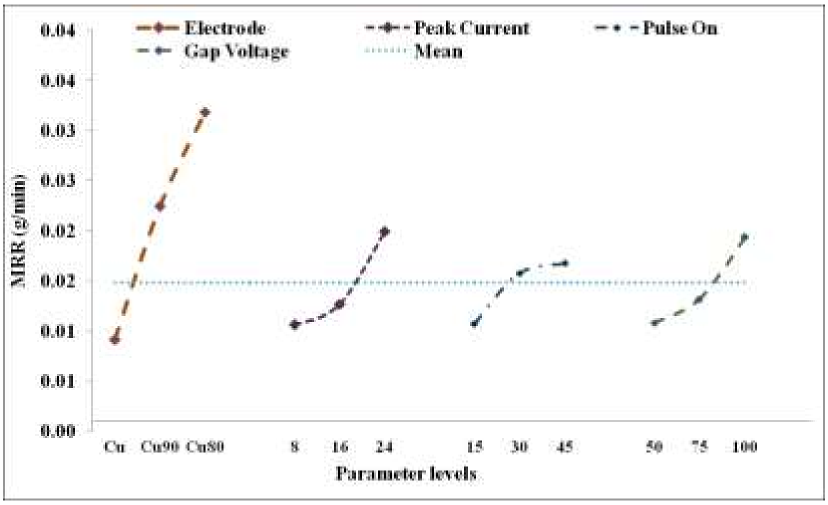

Figure 6. Influences of input parameters on MRR

Influences of Input parameters on TWR:

The effect of input parameters on TWR is displayed in figure 7.The figure clears that PM based tools produce lower TWR when there is an increase in percentage of titanium carbide and zirconium silicate. Since, increasing percentage of compositions increases the wear resistance among particles and increases the porosity on the tools. Therefore, connectivity of current gets disbursed when it is applied on the machining zone [32]. This character of tool electrodes leads to the less TWR on PM tools at higher level of parameter combinations. However, the percentage of titanium carbide and zirconium silicate at middle stage electrode i.e. 5 % TiC and 5 % ZrSiO4 shows the increased TWR with increasing of parametric range. It is due to the fact that titanium carbide provides the additional energy to the electrode to pass the current by its conductivity nature [26]. Therefore, at middle stage of composite electrodes produces the higher TWR. Also, due to the high spark energy of tool higher TWR has been obtained with the higher peak current, pulse on time and gap voltages.

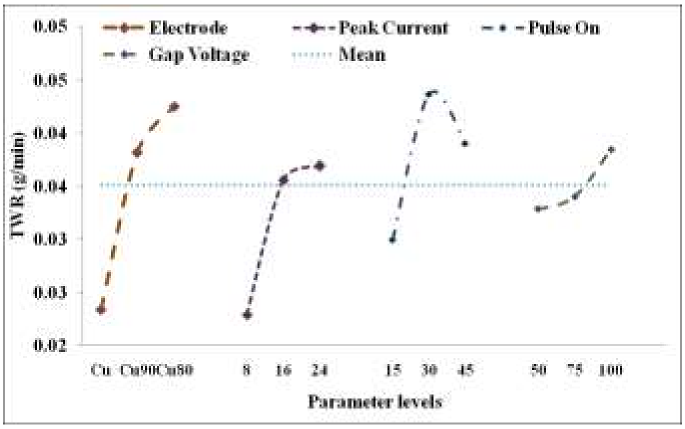

Figure 7.Influences of input parameters on TWR

Influencesof Input parameters on SR:

The effect of input parameters on the SR is displayed in figure 8. The SR shows the increasing trend of graph with increase in parameters values. Better surface finish is noticed with plain copper tool than other PM based composite tools. The PM composite tool produces the crater surfaces and it becomes causes for higher MRR. The higher craters exhibit less surface finish and elements of the tool transferred over the machined surfaces. Hence, surface finish of the machined area leads to the poor with PM composite tools than plain copper tool [33]. Also, the increasing of peak current, pulse on time and gap voltage cause for increasing of spark energy on the machining zone which leads the excess material removal on the work material [34]. The SEM image of machined area showed in figures 9 & 10 for first and second optimal combinations. Furthermore, the machined products (debris) are deposited over the crater surface due to the improper flushing and form the recast layer on machined surface.

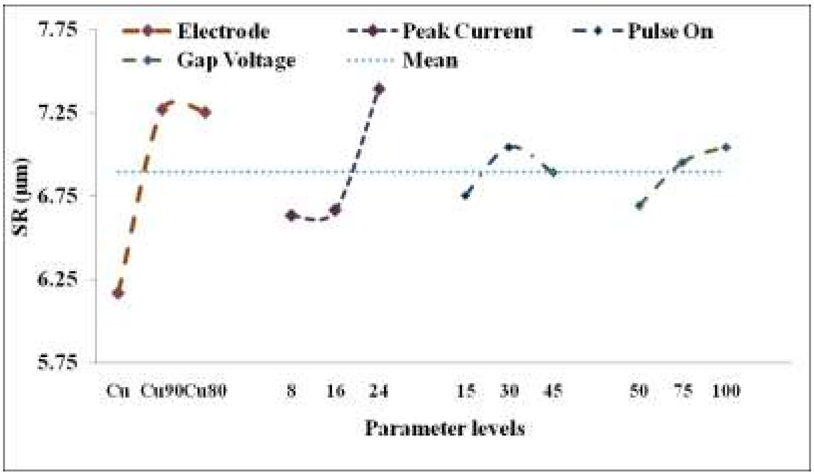

Figure 8.Influences of input parameters on SR

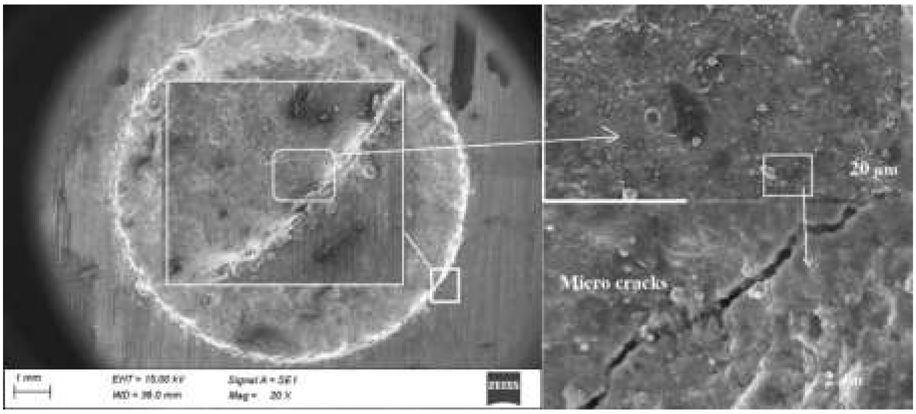

Figure 9. SEM image of 1st optimal combination

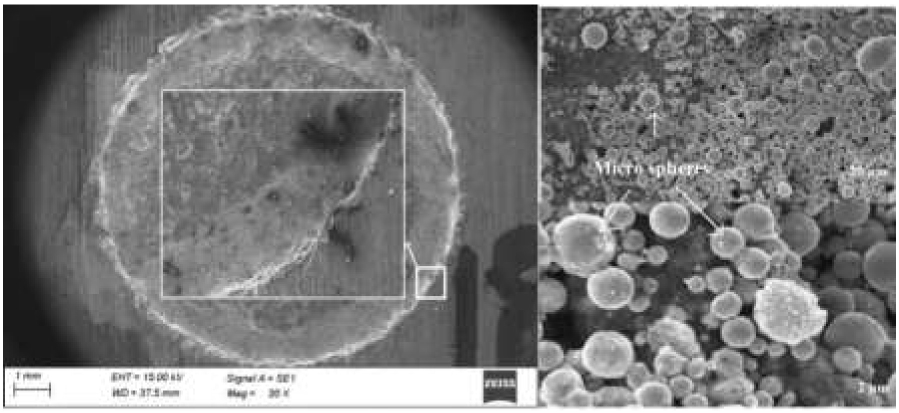

Figure 10. SEM image of 2nd optimal combination

TOPSIS

The output values of EDM such as MRR, TWR and SR through PM based tools are optimized using TOPSIS technique. Equation 1- 8 has been used to obtain the preference value for the experimentations. Equal weights are assigned to all output responses under ideal condition. The preferences values (Pi) and their ranking orders are represented in table 4. The outcomes of the research are converted from multi objective optimization to single attribute optimization through combining method of Taguchi's and TOPSIS. The furthest preference value is termed as optimal parameter solution and maximum rank is considered as first optimal solution. Therefore, it is observed that experimental run 17th (0.6735) is chosen as the best optimal parameter solution for the best performance of EDM due to the highest Pi value. The experimental runs 4th(0.6714) and 10th(0.6259) show the second and third best optimal parameter combinations. Hence, the best optimal solution is found to be that Cu_{90} $(TiC)_5$ $(ZrSiO_4)_5$ PM based tool, E8 Amp peak current, 15 µs pulse on time and 75 V gap voltage using TOPSIS.

Table 4. TOPSIS ranking

Ex.No	Yi +	Yi -	Pi (Preference value)	Rank
1	0.4504	0.2039	0.3116	13
2	0.4836	0.2561	0.3462	12
3	0.3388	0.3187	0.4847	5
4	0.2393	0.4890	0.6714	2
5	0.4100	0.1815	0.3068	14
6	0.3777	0.2520	0.4002	8
7	0.4281	0.1752	0.2904	16
8	0.4933	0.2032	0.2917	15
9	0.4773	0.3111	0.3946	9
10	0.2779	0.4649	0.6259	3
11	0.3970	0.2512	0.3876	10
12	0.4263	0.1713	0.2866	17

13	0.4042	0.2556	0.3874	11
14	0.2920	0.3462	0.5425	4
15	0.3479	0.2664	0.4337	7
16	0.4014	0.3309	0.4519	6
17	0.1972	0.4068	0.6735	1
18	0.4450	0.1545	0.2578	18

Table of ANOVA for TOPSIS

ANOVA is the prominent method to determine the important and insignificant factor. The Pi values of PM based tools are statically analyzed using ANOVA and examined the influences of each and every parameter over the output responses. In addition, the F- test outcomes are used to identify the most important factor to attain the better performance. Table 5 clears that pulse on time plays a major role which contributes around 46.8 % on the machining performance. The next important factor is tool electrode which controls the machining performances about 27.7 %.

Table 5.Table of ANOVA for TOPSIS

Machining parameter Symbol	DOF	SS	MS	F test	% Contri
TE	2	0.0835	0.0418	2.9863	27.76
PC	2	0.0417	0.0209	1.4913	13.86
PT	2	0.1410	0.0705	5.0434	46.89
GV	2	0.0123	0.0062	0.4406	4.09
E	9	0.1258	0.0140		7.38
Total	17	0.4044	0.0238		100

GRA

In GRA method, outcomes of EDM such as MRR, TWR and SR for various tools are normalized using equations 9 and 10. Equations 11& 12are used to determine the GRC and GRG respectively for all conducted experiments. Equal weights are assigned for all responses. GRG and its rankings are displayed in table 6. The furthest GRG value has been considered as optimal parameter solution. Therefore, based on the table, the experimental run 4th (0.7887) is the best optimal parameter solution and experimental runs 17th(0.7868) and 16th (0.7773) are the next best optimal parameter solutions through GRA method. Hence, the optimal parameter solution found to be that Cu_{90} $(TiC)_5$ $(ZrSiO_4)_5$ PM based tool, 8 Amp peak current, 15 µs pulse on time and 75 V gap voltage using GRA.

Table 6.GRG ranking

Ex.No	GRC			GRG	Rank
	MRR	TWR	SR		
1	0.5729	0.5286	1.0000	0.5508	18
2	0.5000	0.7407	0.9470	0.6204	11
3	0.7254	0.5258	0.8074	0.6256	10
4	1.0000	0.5773	0.7314	0.7887	1
5	0.5832	0.5955	0.6325	0.5894	14
6	0.5708	0.7279	0.7336	0.6493	8
7	0.5703	0.5771	0.7259	0.5737	17
8	0.5007	0.6984	0.7067	0.5996	12
9	0.5023	0.9651	0.6148	0.7337	6

10	0.9745	0.5603	0.5657	0.7674	4
11	0.5585	0.7725	0.6117	0.6655	7
12	0.6010	0.5536	0.5398	0.5773	16
13	0.6839	0.5000	0.5624	0.5919	13
14	0.6484	0.8708	0.5465	0.7596	5
15	0.6742	0.6037	0.5000	0.6389	9
16	0.5545	1.0000	0.5446	0.7773	3
17	0.7568	0.8167	0.6063	0.7868	2
18	0.5691	0.5983	0.5010	0.5837	15

Table of ANOVA for GRG

The GRG results of various tools are statically analyzed using ANOVA that is presented in table 7. According to the outcomes of results for PM based tools are optimized using GRA method. Therefore, peak current shows the most significant contribution around 39.3 % on machining performance. The next significant parameter is that pulse on time which contributes on performances around 36.8 %.

Table 7.Table of ANOVA for GRG

Machining parameter Symbol	DOF	SS	MS	F test	% contri
TE	2	0.0098	0.0049	0.284	8.03
PC	2	0.0479	0.024	17.20	39.30
PT	2	0.0449	0.0225	16.12	36.82
GV	2	0.0068	0.0034	2.43	5.56
E	9	0.0125	0.0014		10.27
Total	17	0.1219	0.0072		100

The ranking values of TOPSIS and GRA technique are presented as a graph in figure 8 which is plotted for experimental run Vs TOPSIS and GRA values. The experimental runs 17th and 4thshow the first two optimal combinations for the best performance of EDM using TOPSIS and GRA method. Moreover, in both techniques, they provide the same parametric combination for machining. Also, 10th and 16th experimental runs show the third optimal combinations using TOPSIS and GRA method.

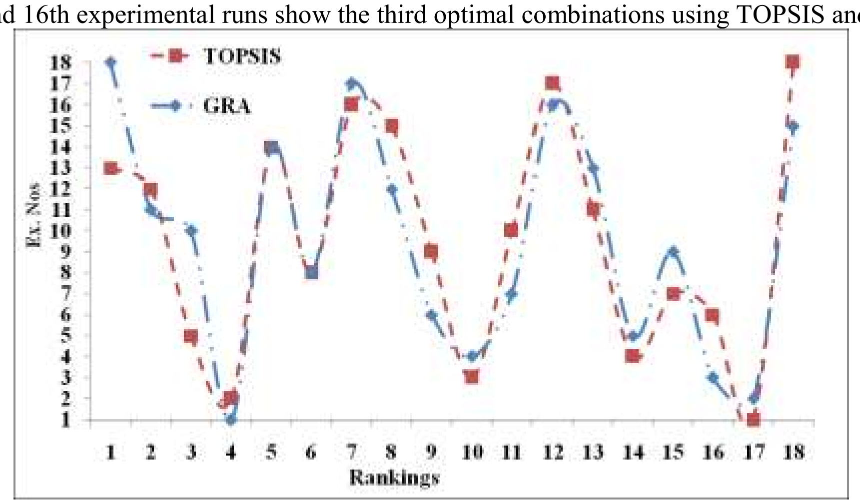

Figure 11. Comparison of TOPSIS and GRA ranking

CONCLUSIONS

This research work is aim to explore the benefits and performance measures of powder metallurgy based copper electrodes in EDM process. Two electrodes in different reinforcement combinations such as Cu_{90} (TiC)5 (ZrSiO4)5 and Cu $_{80}$ (TiC)10 (ZrSiO4)10 are prepared using PM technique and their results are compared with plain Cu electrode. The experiments are conducted based on the L 18 OA and optimization techniques such as TOPSIS and GRA are used to find the optimal solution. The results found from the experiments are MRR and TWR increase with increasing of percentage of reinforcements in the composite electrodes. The optimization techniques such as TOPSIS and GRA produce the same optimal parametric solution for lesser TWR, SR and higher MRR. Hence, the 17th experimental run is proposed as optimal parameter combination that Cu_{90} $(TiC)_5$ $(ZrSiO_4)_5$, E8 Amp peak current, 15 µs pulse on time and 75 V gap voltage. In addition, based on the ANOVA table of TOPSIS, pulse on time plays a major role which contributes around 46.8 % on the machining performance and peak current shows the most significant contribution around 39.3 % on machining performance using GRA values. Therefore, Cu_{90} composite tool is more appropriate for the higher MRR and less TWR. Furthermore experiments can be conducted with various concentrations of reinforcements and different work materials to understand behavior of machining.

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