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Experimental Investigation into Powder Mixed EDM of High Speed Steel T1 Grade by GRA Approach

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ABSTRACT
This Paper is developed an innovative process of powder mixed electrical discharge machining of high speed steel T1 grade and conducted an investigational to optimize the machining parameters associated with multiple performance characteristics using Grey relational analysis. Machining of high speed steel T1 grade is difficult process via conventional machining however; it can be easily machined by electric discharge machining. Carefully selected parameters give the optimum results. In this experimental work input parameters pulse on-time, discharge current, tool material and powder concentration are selected. The effect of input parameters

viz material removal rate, tool wear rate and surface roughness are investigated. Grey relational analysis and analysis of variance are performed to optimize the input parameters and better output results. In this experimentation, increment of tool wear rate by 63.24%, material removal rate by 52.18% and surface roughness by 42.49%.

Keywords: Electric Discharge Machining, Powder Mixed EDM, High Speed Steel, GRA

Abbreviation: EDM, GRA

1. INTRODUCTION

Electrical discharge machining (EDM) is one of the most extensively used non-conventional material removal processes (Jingyu PEI et al. 2016). Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been a distinctive advantage in the manufacture of mould, die, automotive, aerospace and surgical components which are difficult to manufacture by conventional machining (NaotakeMohri et al. 1995). In mechanism of EDM, unwanted parts of work-piece is removed by the high temperature spark and many defects such as cracks, porosity, residual stress, improper recast layer are found due to high temperature variation (Lin et al. 2008). Hence an innovative technique known as powder mixed EDM has been performed in the presence of foreign particles suspended in dielectric medium to overcome some of the limitations of conventional EDM (Kumar et al. 2011). The mechanism of PMEDM is totally different from the conventional EDM (Furutani K et al. 2001). A suitable material in powder form is mixed into the dielectric fluid of EDM. When a suitable voltage is applied, the spark gap filled up with additive particles and the gap distance setup between tool and the work-piece increased from 25-50 to 50-150 mm (Jeswani ML 1981). The powder particles get energized and behave in the zig-zag fashion. These charged particles are accelerated by the electric field and act as conductors. The powder particles arrange themselves under the sparking area and gather in clusters. The chain formation helps in the bridging the gap between both the electrodes, which causes the early explosion. Faster sparking within discharge takes place causes faster erosion from the work-piece surface (S.Chakraborty et al. 2014). The chemical Composition of the high speed steel T1 grade has been shown in Table 1.Some important properties of high speed steel T1 grade are shown in Table 2. Some important properties of Tool Copper and graphite has been shown in Table 3. Copper and Graphite Electrodes (19mm diameters and 60mm length) has been depicted in Figure 1.

In the experiment, selected parameters having two different level shown in Table 2. Design of experiment is prepared by Minitab 6.7 software in which L_{16} orthogonal array is used. The levels are selected by pilot experiments. For calculating MRR and TWR the initial and final weight of tool and work-piece sample respectively measured by weight machine and surface roughness of work-piece sample is check by SM (RT-10) surface roughness tester.

Table 1 Chemical Composition of high speed steel T1 grade

%age	0.655	0.281	0.330	0.022	0.011	4.44	0.247	1	0.129	0.577	1.04	17.25	74.43
Element	C	Si	Mg	P	S	Cr	Mo	Ni	Co	Ti	V	W	Fe

Table 2 Important properties of High Speed Steel (T1 Grade)

Properties	High Speed Steel (T1 grade)
Density(g/cm^3)	8.67
Poisson's Ratio	0.27-0.30
Thermal Conductivity(W/m-K)	19.9
Modulus of Elasticity Tension(GPa)	190-210

Table 3 Properties of Tool Materials

Properties	Copper	Graphite
Density (g/cm^3)	8.96	2.266
Melting point (˚C)	1085	3652
Thermal conductivity (W/m-K)	385	25-470

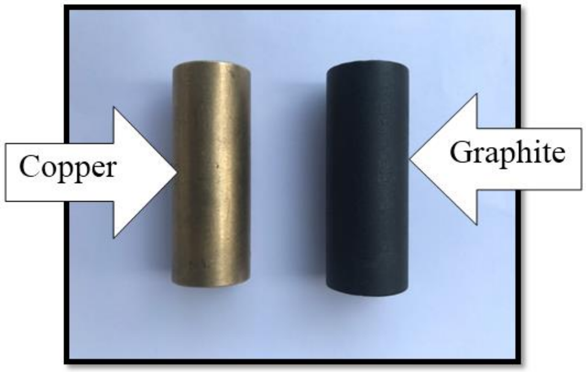


Figure 1 Copper and Graphite Electrodes (19mm diameters and 60mm length)

Figure 2 Schematic Diagram of Powder mixed EDM

2. MATERIAL AND METHODS

Selected parameters and levels are shown in Table 4. For the design of experiment orthogonal array L_{16} is used and design is prepared by Minitab 6.7 software. The design of experiment is shown in Table 5. All the experiments are performed according to the design experiment.MRR and TWR are calculated by the equation 1 and equation 2, in which density of work material ρ is 8.67 gm/cm^3, $W_i$is initial weight, W_f final weight after processing, t is time take in machining. T_i initial and T_f weight of tool and ρ = Density of copper 8.96 gm/cm^3 and Density of graphite 2.266 gm/cm^3.

$$MRR = \frac{W_i - W_f}{\rho \, X \, t} \, 1000 \, (mm^3/min)\ldots\ldots(1)$$

$$TWR = \frac{T_i - T_f}{\rho \, X \, t} \, 1000 \, (mm^3/min)\ldots\ldots(2)$$

Surface roughness is measured in Ra, it is the universally recognised and most used international parameter of roughness. It is the arithmetic mean of the absolute departure of the roughness profile from the mean line.

After machining the MRR and TWR are calculated and SR is checked, machining data is shown in Table 6. In which MMR and TWR is calculated in mm^3/min and surface roughness in Ra. Powder Mixed EDM sample of high speed steel T1 grade has been depicted in Figure 3.

Table 4 Different input or controllable parameters and their levels

Factors		Tool	Discharge Current (A)	Pulse On-Time (μs)	Powder concentration
Levels	Level-1	Copper	10	30	10%
	Level-2	Graphite	20	40	20%
Fixed Parameters					
Dielectric Fluid	Kerosene Oil		**Flushing Pressure**	18 kg/cm^2	
Polarity	Straight		**Open Circuit Voltage**	240 V	
Abrasive	SiC		**Abrasive Grit Size**	400	

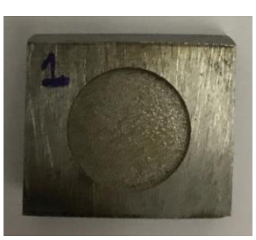
Table 5 Design of Experimentation (Orthogonal Array L_{16}) and their levels

S.No	Pulse On Time	Discharge Current	Tool Material	Powder Concentration
1	30	10	Copper	10%
2	30	10	Copper	20%
3	30	10	Graphite	10%
4	30	10	Graphite	20%
5	30	20	Copper	10%
6	30	20	Copper	20%
7	30	20	Graphite	10%
8	30	20	Graphite	20%
9	40	10	Copper	10%
10	40	10	Copper	20%
11	40	10	Graphite	10%

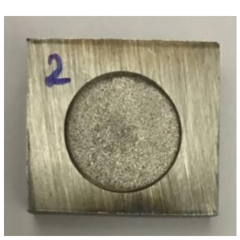
12	40	10	Graphite	20%
13	40	20	Copper	10%
14	40	20	Copper	20%
15	40	20	Graphite	10%
16	40	20	Graphite	20%

Table 6 Design of Experimentation (orthogonal Array L_{16}) and their levels

Trail	**High Speed Steel (T1 Grade)**		
	MRR (mm³/min)	**TWR (mm³/min)**	**SR (Micron)**
1.	11.243	3.302	2.19
2.	12.276	3.199	2.11
3.	9.797	4.861	3.09
4.	9.236	4.900	3.26
5.	16.401	3.751	2.78
6.	14.301	3.851	2.59
7.	13.452	5.621	3.62
8.	13.906	5.530	3.39
9.	13.188	3.601	2.39
10.	13.456	3.500	2.31
11.	11.677	5.434	3.28
12.	11.132	5.300	3.36
13.	20.926	4.008	2.99
14.	19.428	3.901	3.16
15.	15.326	5.758	3.73
16.	13.986	5.501	3.59



Sample 1



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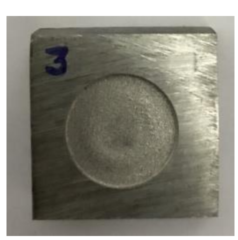
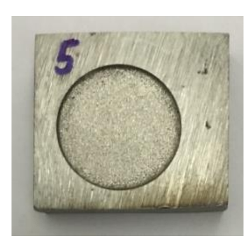


Sample 3

Sample 4



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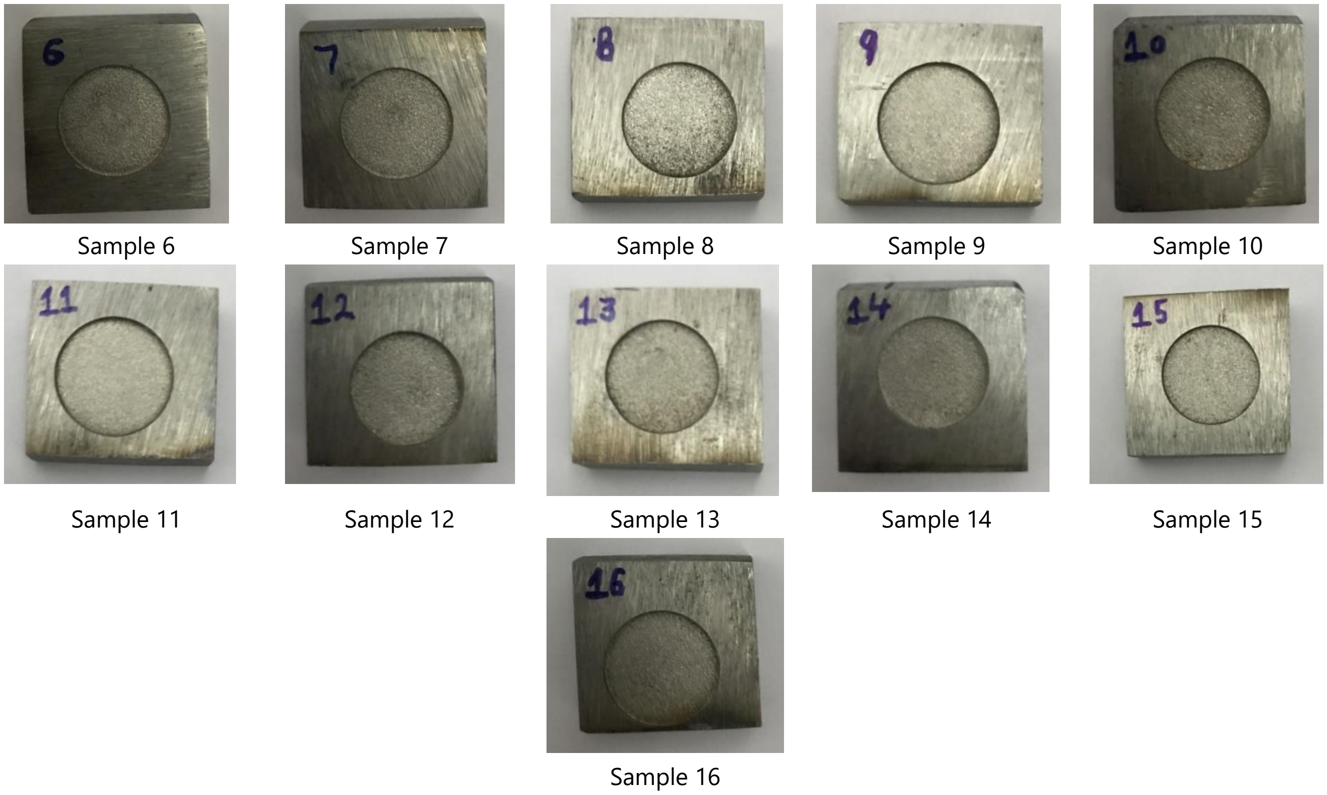

Figure 3 Powder Mixed EDM sample of high speed steel T1 grade

3. RESULTS AND DISCUSSION

In grey relation analysis, data pre-processing is necessary to sequence scatter range. Data pre-processing is a process in which original sequence is transferred into comparable sequence. The experiment results are normalized in the range between zero (0) and one (1). Depending on output parameters, data pre-processing methodologies are adopted (Lin et al. 2002; Lin & Lee 2009; You et al. 2017). MRR is the governing output parameter in EDM, which decided the machinability of work material under deliberation. "Larger-the-better" characteristic is used for MRR to normalize the original sequence by equation 3.

$$X_i^*(k) = \frac{X_i(K) - MinX_i(K)}{MaxX_i(K) - MinX_i(K)} \quad \text{................................(3)}$$

Where, $X_i^*(K)$ is the sequence after the data processing, $X_i\ (K)$ is the comparability sequence, K=1 for MRR; i= 1,2,3.........16 for experiment number 1 to 16.

TWR and SR are the important measure of EDM; these output parameters are representing the machining accuracy under selected input parameters (Patil & Patil 2016; Das et al. 2016). To get the optimum performance the "Smaller-the-better" characteristic has been preferred to normalize the original sequence date by equation 4.

$$X_i^*(K) = \frac{MaxX_i(K) - X_i(K)}{MaxX_i(K) - MinX_i(K)} \quad \text{..................................(4)}$$

Where, $X_i^*(K)$ is the sequence after the data processing, $X_i(K)$ is the comparability sequence, K=2, K=3 for TWR and SR; i= 1,2,3.........16 for experiment number 1 to 16. $X_i^*(K)$ is the value after grey relational generation, Min $X_i(K)$ and Max $X_i(K)$ are the smallest and largest value of $X_i(K)$. After normalized MRR, TWR and SR of High Speed Steel T1 grade comparable sequence is shown in the Table 7.

Now $\Delta_{0i}(K)$ is the deviation sequence between reference sequence $X_i^{0}(K)$ and the comparability sequence $X_i^{*}(K)$ (Ahmad et al. 2016).Deviation sequence is calculate by the equation 5 and maximum and minimum difference is found, K=1 and 2 and i= 1, 2, 3…16.

$$\Delta_{0i}(K) = \left| X_0(K) - X_i(K) \right| \text{......................................(5)}$$

The deviation sequence table is shown in the Table 8, Maximum (ΔMax) and Minimum (ΔMin) are obtained and shown below.

$$\Delta Max = \Delta_{04}(1) = \Delta_{15}(2) = \Delta_{15}(3) = 1$$

$$\Delta Min = \Delta_{13}(1) = \Delta_{02}(2) = \Delta_{02}(3) = 0$$

After per-processing data, the next step in calculate the Grey relational coefficient and Grey relation grade with the pre-processed data (Lin et al. 2009). It defines the relationship between ideal and actual normalized results. Grey relational coefficient ξ can be expressed as equation 6 is shown below.

$$\xi_i(K) = \frac{\Delta Min + \rho \Delta Max}{\Delta_{0i}(K) + \rho \Delta Max} \text{......................................(6)}$$

Where, $\Delta_{0i}(K)$ is the deviation sequence of the reference sequence $X_i^{0}(K)$ and the comparability sequence, ρ is distinguishing or identification coefficient. In this calculation ρ =0.5 because all parameters are given equal preference (Lin 2012). The Grey relation coefficient for each experiment of the L16 orthogonal array is calculated by using equation 6 and shown in Table 9. After obtaining the Grey relation coefficient, the Grey relation grade γ_i is obtained by averaging the Grey relation coefficient corresponding to each performance characteristic and represent by $\xi_i(1)$, $\xi_i(2)$, $\xi_i(3)$ Equation 7 (Manivanna et al. 2011) show the general formula of Grey relation grade and equation 8 is for three output parameters, shown in Table 7.

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \{\xi_i(K)\} \text{..(7)}$$

$$\gamma_i = \frac{1}{3} \{\xi_i(1) + \xi_i(2) + \xi_i(3)\} \text{.......................................(8)}$$

The higher value of Grey relation grade is represent that the corresponding experiment result is much closer to the ideally normalized value. Experiment number 02 gets the best multiple performance characteristics among the 16 experiment because it has the highest value of grey relation grade. Now the experimental design is orthogonal, it is possible to separate out the effect of each parameter on the basis of Grey relation grade. Mean of Grey relation grade is calculated for level 1 and 2 by averaging the Grey relation grade of the experiment 1 to 8 and 9 to16 are shown in Table 8. The mean of Grey relation grade for pulse On-time, discharge current, tool Material and Powder concentration are calculated in same manner. The total mean of Grey relation grade for 16 experiments is also shown in the Table 10. *Level for optimum grey relational grade. Optimum level parameters are find out from response table and shown in the Figure 4. Larger value of Grey relation grade is closer to the ideal value. Therefore, the optimum parameters setting for higher MRR and lower TWR and SR are $A_1B_1C_1D_2$.

Furthermore, Analysis of variance (ANOVA) is performed on Grey relation grade to achieve contribution of each input parameter affecting the output parameters. ANOVA for Grey relational grade is shown in Table 11. In addition, F-test is also used to find out the percentage contribution of each parameter. From Table 11 it is clear that material of tool have the significant role in the machining which have 89.43% contribution of tool material, 2.37% contribution of discharge current, 0.19% contribution of pulse on-time and 0.001% contribution of powder concentration in the machining of High Speed Steel T1 grade.

After analysis input parameters having percentage contribution in Grey Relational Grade according to the below sequence are 89.43% tool material, 2.37% discharge current, 0.19% pulse on-time and 0.001% powder concentration. It shows that tool material has maximum contribution and powder concentration have minimum contribution in optimum machining parameters. Percentage contribution of input parameters for output response is shown in Figure 5.After Grey Relational Analysis the comparison between the 1st trial orthogonal array and grey relational analysis output parameters, gives improvement in the output response. It has 63.24% in TWR, 52.18% in MRR and 42.49% in SR.

Table 7 The sequence of each performance characteristic after data processing

Trail	High Speed Steel (T1 Grade)		
	MRR	TWR	SR
Reference Sequence	1	1	1
1.	0.171685	0.95975	0.950617
2.	0.260051	1	1
3.	0.04799	0.350528	0.395062
4.	0	0.335287	0.290123
5.	0.612917	0.784291	0.58642
6.	0.433276	0.745213	0.703704
7.	0.36065	0.053537	0.067901
8.	0.399487	0.089097	0.209877
9.	0.338067	0.842907	0.82716
10.	0.360992	0.882376	0.876543
11.	0.208811	0.126612	0.277778
12.	0.16219	0.178976	0.228395
13.	1	0.683861	0.45679
14.	0.871856	0.725674	0.351852
15.	0.520958	0	0
16.	0.40633	0.10043	0.08642

Table 8 The deviation sequences

Deviation Sequence	$\Delta_{0i}(1)$	$\Delta_{0i}(2)$	$\Delta_{0i}(3)$
1.	0.828315	0.04025	0.049383
2.	0.739949	0	0
3.	0.95201	0.649472	0.604938
4.	1	0.664713	0.709877
5.	0.387083	0.215709	0.41358
6.	0.566724	0.254787	0.296296
7.	0.63935	0.946463	0.932099
8.	0.600513	0.910903	0.790123
9.	0.661933	0.157093	0.17284
10.	0.639008	0.117624	0.123457
11.	0.791189	0.873388	0.722222
12.	0.83781	0.821024	0.771605
13.	0	0.316139	0.54321
14.	0.128144	0.274326	0.648148

15.	0.479042	1	1
16.	0.59367	0.89957	0.91358

Table 9 The calculated Grey Relational Grade and its order in the optimization process

Expt. No.	Grey Relational Coefficient			Grey Relation Grade $\gamma_m = \frac{1}{3}\{\xi_i(1)+\xi_i(2)+\xi_i(3)\}$	Rank
	$\{\xi_i(1)\}$	$\{\xi_i(2)\}$	$\{\xi_i(3)\}$		
1.	0.376417	0.925497	0.910112	0.737342	2
2.	0.403242	1	1	0.801081	1
3.	0.34435	0.434982	0.452514	0.410615	9
4.	0.333333	0.42929	0.413265	0.391963	12
5.	0.563645	0.698608	0.547297	0.603183	7
6.	0.468725	0.662439	0.627907	0.586357	8
7.	0.438847	0.345671	0.349138	0.377885	16
8.	0.454333	0.354383	0.38756	0.398759	10
9.	0.430317	0.760928	0.743119	0.644788	5
10.	0.438979	0.809554	0.80198	0.683504	4
11.	0.38724	0.364063	0.409091	0.386798	14
12.	0.373745	0.378494	0.393204	0.381814	15
13.	1	0.612641	0.47929	0.69731	3
14.	0.795996	0.645723	0.435484	0.625734	6
15.	0.510703	0.333333	0.333333	0.392457	11
16.	0.457176	0.357253	0.353712	0.38938	13

Table 10 Response Table for the Grey Relational Grade

Symbol	Machining Parameters	Grey Relation Grade		Main Effect (Max-Min)	Rank
		Level 1	Level 2		
A	Pulse On-Time	0.5384*	0.5252	0.0132	3
B	Discharge Current	0.5547*	0.5089	0.0459	2
C	Tool Material	0.6734*	0.3912	0.2812	1
D	Powder Concentration	0.5313	0.5323*	0.0010	4

Total mean value of the Grey Relational Grade γ_m = 0.531811

Table 11 ANOVA of Gray Relation Grade

Parameter	Degree of Freedom	Sum of Squares	Mean Squares	F Ration	Percentage Contribution
Pulse On-Time	1	0.000694	0.000694	0.27	0.19%
Discharge Current	1	0.008411	0.008411	3.27	2.37%
Tool Material	1	0.316302	0.316302	123.08	89.43%
Powder Concentration	1	0.000004	0.000004	0.00	0.001%
Error	11	0.028270	0.002570		7.99%
Total	15	0.353681			

Table 12 Improvement in Grey relational grade with optimized EDM machining parameters

Condition Description	Optimal Machining Parameters	
	Machining Parameters in First trail of OA $A_1B_1C_1D_1$	Grey Relational Analysis $A_1B_1C_1D_2$
MRR (mm^3/min)	11.243	17.133 (52.18%)
TWR (mm^3/min)	3.302	1.252 (63.24%)
SR (micron)	2.19	1.26 (42.49%)
Grey Relational Grade	0.737342	0.368671

` Improvement in Grey relational grade = 0.3291

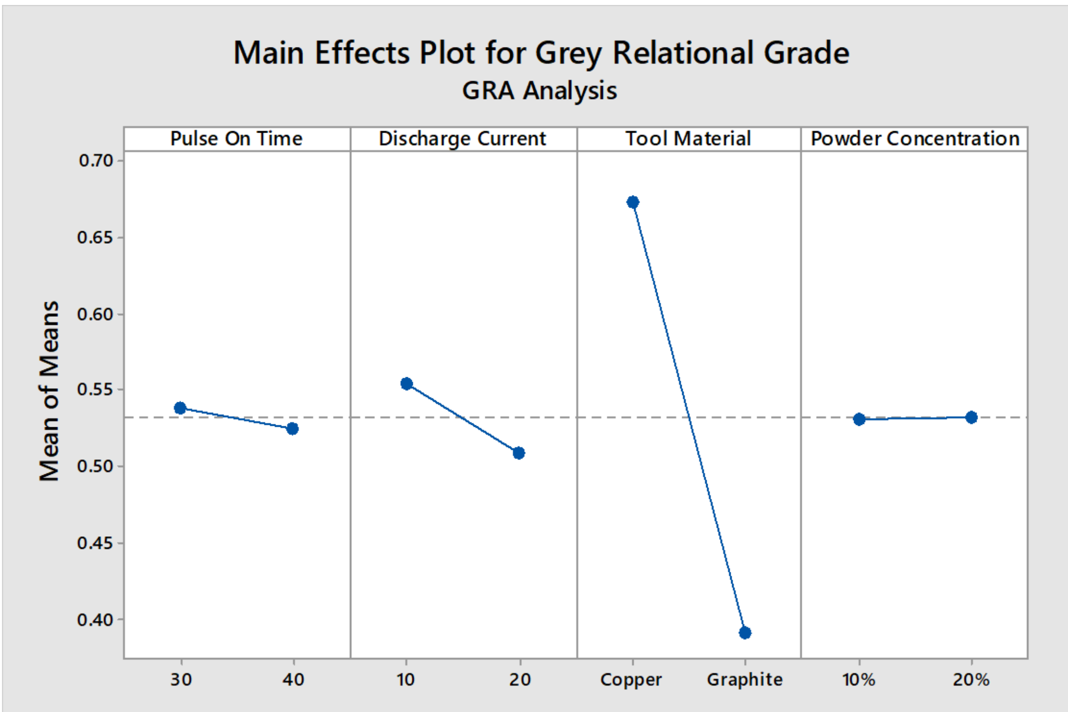

Figure 4 Effect of EDM parameters on the multiple-performance characteristics

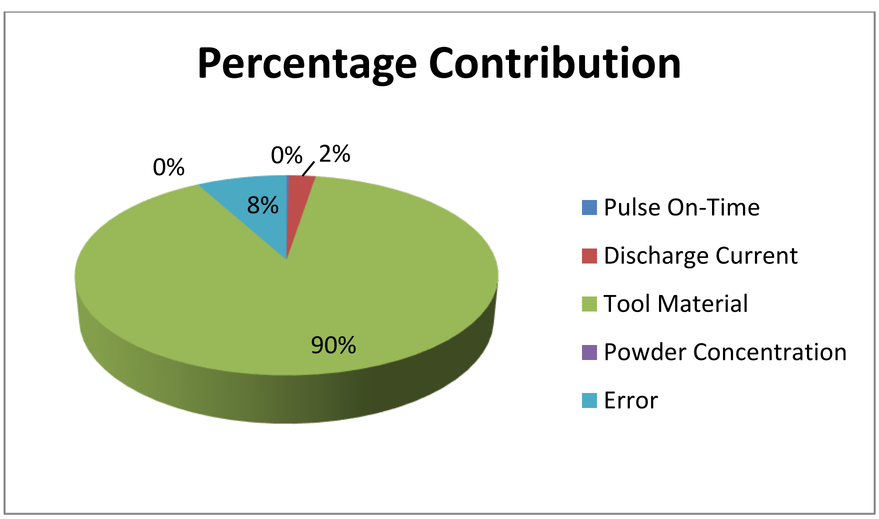

Figure 5 Percentage contribution of input factors on Grey Relational Grade

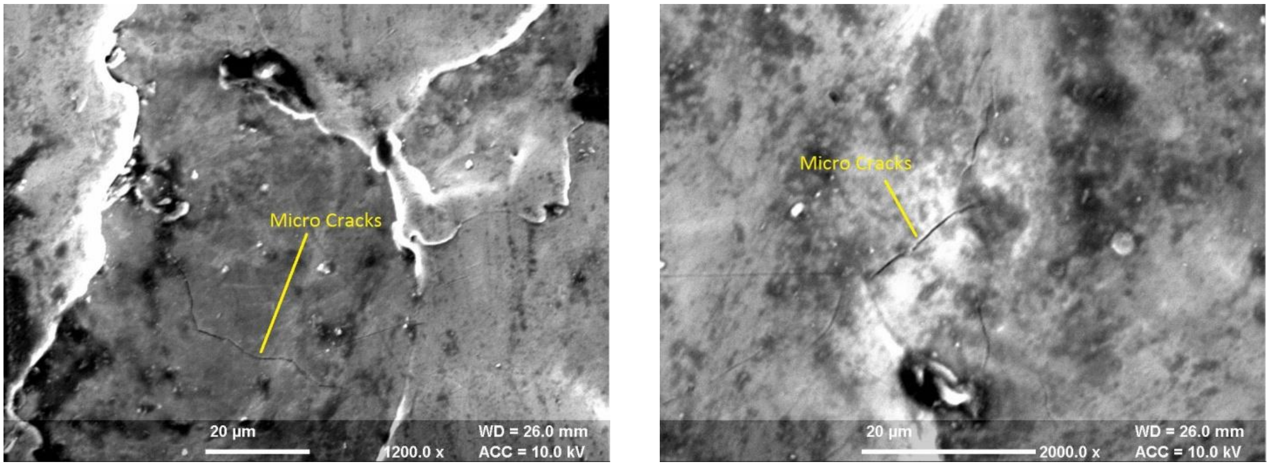

Figure 6 SEM image of (A_1, B_1, C_1, D_1) at magnification 1200X and 2000X

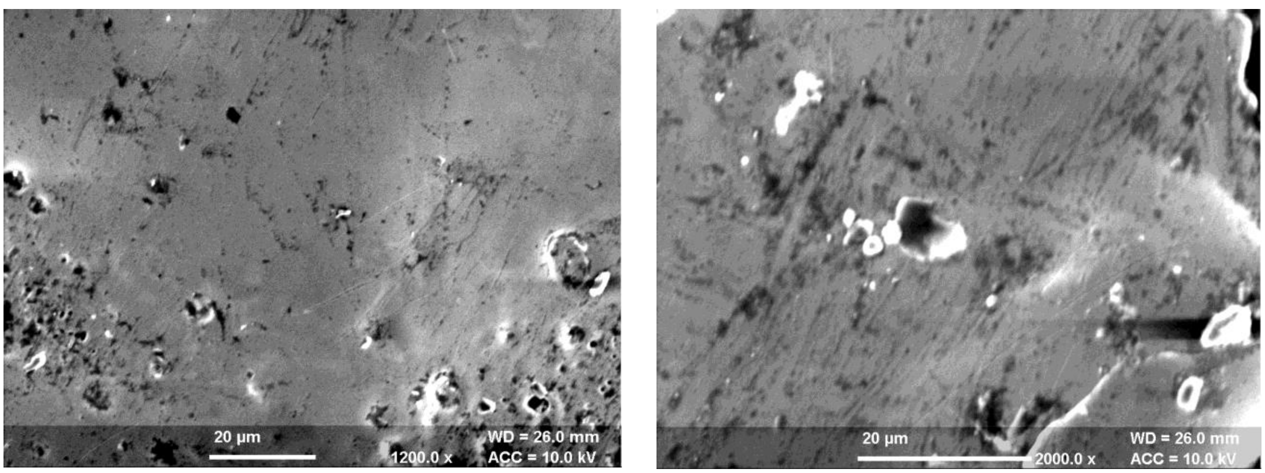

Figure 7 SEM image of (A_1, B_1, C_1, D_2) at magnification 1200X and 2000X

After getting the optimum parameters for machining, the experiment is performed by those input setting (A_1, B_1, C_1,D_1).Figure 6 shows the Scanning electron microscope (SEM) images of high speed steel T1 grade with machining setting (A_1, B_1, C_1,D_1). In which machining by PMEDM is performed and some crack are also found on the work surface. In other hand in Figure 7 the PMEDM of high speed steel T1 grade is performed by optimum parameters which are found by Grey relational analysis $A_1B_1C_1D_2$, there is smoother and crack free surface.

SEM images of figure.4 are at (A_1, B_1, C_1, D_1) where A_1 pulse on-time is 30µs, B_1 discharge current is 10Ampere, C_1 tool material is copper and D_1 powder concentration is 10%.

SEM images of figure.5 are at (A_1, B_1, C_1, D_2) where A_1 pulse on-time is 30µs, B_1 discharge current is 10Ampere, C_1 tool material is copper and D_2 powder concentration is 20%.

4. CONCLUSION

The optimum machining parameters are identifying by Grey relational grade for multiple performance characteristics that is MRR, TWR and SR. This experimental research paper presented the multi-objective optimization of electric discharge machining parameters of High Speed Steel T1 grade by Grey relational analysis method. Following conclusions are concluded from the experimentation analysis.

1. The optimum value of MRR of High Speed Steel T1 is 18.5436mm^3/min and is gained by copper tool with pulse on-time 40µs, discharge current of 20 Amperes and powder concentration of 10%.
2. The optimum value of TWR in case machining of High Speed Steel T1 is gained by copper tool under pulse on-time 30µs, discharge current of 10 Amperes and powder concentration of 20%.
3. The optimum value of SR for machining of High Speed Steel is 2.213 microns is achieved by tool of copper at pulse on-time 30µs, discharge current of 10 Amperes and powder concentration of 20%.
4. Highest MRR for machining High Speed Steel T1 is achieved when using copper as tool in EDM.
5. Minimum MRR is achieved while machining with graphite tool.
6. Maximum tool wear rate is achieved when Graphite tool is used in EDM.
7. Minimum tool wear rate is achieved when copper tool is used in EDM.
8. Minor cracks are formed on work-piece surface while using graphite as a tool and surface roughness is very high.
9. Graphite tool gives the poor MRR as well as TWR. After SEM analysis, we find that the graphite particles are also deposited on the machined surface.

FUTURE ISSUES

To study the performance characteristics like material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) of high speed steel (T1) grade by using powder mixed electric discharge machining. The result of the study will be beneficial for the industrial applications and manufacturing industries to get better results for single output response. The obtained results have also been modeled for the use in manufacturing industries. Rey relational analysis for process optimization of powder mixed electric discharge machining of high speed steel (T1) grade has been conducted to improve the quality, productivity and machinability of these materials.

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