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Analysis of Powder-Mixed EDM Process Characteristics of Tungsten Carbide alloy by using GRA Technique

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***Abstract:* Abrasive electrical discharge machining of tungsten carbide is performed by using a powder of graphite and alumina mixed in working fluid. Taguchi method is used to predict the optimal choice of EDM parameters like current, powder, pulse on time and pulse off time. After experiments, it has been found that adopted parameters significantly affect the response characteristics like metal removal rate and tool wear rate. Taguchi technique with the grey relational analysis was for optimizing machining operations with multi-process parameters. Optimum process parameter is determined with the help of Taguchi technique using grey relational grade as the performance index. Response table is used to optimize the process parameters. Further, an analysis of variance (ANOVA) study is performed to show the significance and percentage contribution of each factor in the study.**

***Index Terms:* EDM, Electrical, Discharge, Machining, ANOVA, GRG, Optimization**

I. Introduction

Electric discharge machining (EDM) process is an unconventional machining process, where the material removal occurs due to a spark between the tool and workpiece dipped in a dielectric fluid [1]. The spark causes a temperature of about 10,000˚C, which is sufficient to melt and vaporize the material, enabling the process to machine High Strength Temperature Resistant (HSTR) materials and alloys. [1,2]. Being capable of producing intricate geometrical shapes, the process finds its applications in the manufacturing of automotive, aerospace, surgical components and mold & dye-making industry. Although the process has widespread industrial applications, yet it faces limitations due to its low machining efficiency and poor surface finish [3,4].

Therefore, to overcome the limitations mentioned above, several studies have been carried out by several researchers - particularly for better control over the machining parameters. Nowadays, due to advances in technology, and an overall hybrid process called "Powder Mixed Electrical Discharge Machining (PMEDM)" process is being used to overwhelm the limitations of conventional EDM [1, 5]. In PMEDM, the material in powder form is mixed in the dielectric fluid to decrease its insulating strength and increase the spark gap distance between the electrode & workpiece, which allows uniform flushing of debris [6]. Due to this, the process becomes more stable, thereby improving the machining rate and surface finish. Further, the surface produced via PMEDM is found to be having high resistance to corrosion and abrasion. Although the powder mixed EDM process possesses better result than traditional processes, still it lacks swift acceptance in industries. In recent literature, many studies have shown future analysis of process parameters, as a future scope. So, this study is an attempt to optimize various process parameters. Material removal rate (MRR) and tool wear rate (TWR) were taken as output parameters whereas pulse-on, pulse-off, current and powder were taken as input variables.

II. Background and Review

The first study on powder-mixed EDM was published in 1980. The addition of powder particles into dielectric fluid produced better surface finish and machining rate compared to conventional EDM [7]. Research and industrial experts have been continuously working on its parameters to reach an optimum level with respect to various materials. For instance, Kansal et al. [8] executed research development using additives/powders with the EDM process. Mahdavinejad and Mahdavinejad [9] examined the variability of EDM process through machining of WC–Co composite by varying compositions. Sharma and Singh [1] applied RSM optimization technique to optimize process parameters during the EDM process of WC-Co composite. Kung et al. [3] used the RSM technique for optimization of the input variables of WC in powder EDM process and revealed that Al powder mixed in dielectric fluid enhances the efficiency of the EDM process.

It is observed from the above literature reviews, that much work has been undertaken by a number of researchers to explore the PM-EDM of different materials, but very few authors have studied the EDM or PM-EDM of WC material, which prompts the current research to execute the powder mixed EDM of tungsten carbide [10]. For this study, input parameter settings were taken with the help of Taguchi's L27 orthogonal array design. To find the optimum processing parameter, the grey relational grade technique was applied.

III. Experimental Details

Metal powders are added in the dielectric fluid. In order to avoid the powder being mixed with the filtering system, a transparent bath is used. For the enhanced circulation of the powder in the dielectric fluid, a stirrer is used for shaking the powders constantly in the box, and the rpm is controlled by a heavy-duty regulator. Experiments were executed on CNC electric discharge machine. Tungsten carbide was used as workpiece material with composition, W-65.50%, Ti-15.47%, Co-10.07%, Nb-4.69% and Cu-3.66%. Copper was used as a tool electrode, and EDM oil was used as a working fluid.

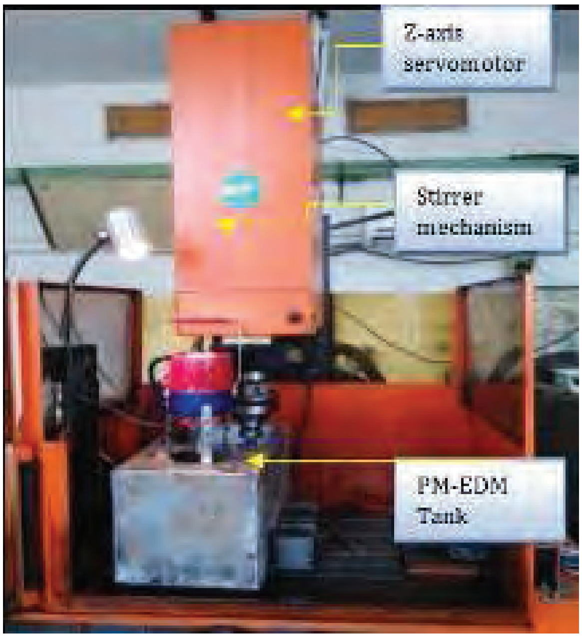

Figure 1. Experimental setup (Model no. T-3822)

Material removal rate (MRR) and tool wear rate (TWR) of the powder EDM process was studied by taking four input parameters, i.e. pulse-on, pulse-off, current and powder.

The input parameters and their levels are shown in Table. 1. The fixed input parameters used in this experiment are:
open circuit voltage (135 ± 5%);
- polarity (+);
- copper tool;
- machining time (10 min);
- powder concentration (15 gm/l).

Four factors and three levels were taken into consideration based on pilot experimentation and literature review. Taguchi's L_{27} orthogonal array was applied to this experiment, as shown in Table 2. Grey relational analysis was used to determine the appropriate selection of machining parameters for experimenting. To evaluate the PM-EDM machining performance, MRR and TWR were calculated after each experiment by using equation 1.

$$\text{MRR or TWR} = \frac{Wi - Wf}{\rho \times t} \times 1000\ \text{mm}^3/\text{min}$$
(1)

w_i, w_f = Initial and Final weight of the sample respectively, t = Period of trials, ρ = Density of sample, MRR and TWR were measured using a digital weighing machine with least count 0.001 gm.

IV. Results and Discussions

In this section, the data of MRR and TWR obtained from 27 experiments as tabulated in Table.2 were analyzed by using Grey Relational Analysis (GRA) technique followed by response tables. At last, ANOVA analysis for mean was performed to show the significant factors and their contributions to the study. Figures 2 shows that MRR and TWR increase with an increase in pulse-on time and current, whereas it decreases with an increase in pulse off time.

TABLE I.
Process Parameters and Their Levels

Factors	Process Parameter	1	2	3
A	Pulse-on time (μs)	30	50	70
B	Pulse-off time (μs)	20	35	50
C	Current (A)	3	5	7
D	Powders	CP	AP	*
CP = graphite Powder; AP = aluminum oxide Powder; 1,2,3 = levels; simple EDM = *, 1.				

With the increase in input discharge energies (pulse-on time and current), the temperature between both the electrodes increases, which helps to melt and evaporate vast amounts of material out from the electrodes, hence increase MRR & TWR. With the mixing of graphite powder and alumina powder MRR increases as compared to simple EDM process. Graphite seems to be most useful to improve material removal rate for PM-EDM of WC. Alumina powder gives low TWR as compared to simple EDM and carbon powder.

Response table for mean data and GRG grade for MRR & TWR are shown in Table 3. For MRR, higher-the-better response characteristic is taken. So a higher value from the response tables has been selected. For TWR, lower-the-better response characteristic is considered. Therefore, the lower value from the response table has been selected. According to response tables, the powder is the most effective process parameter followed by pulse-on time, pulse-off time and current—Star (*) in response table highlights the most significant values. Grey relational grade co-efficient provides the optimum process sequence. The GRG ranking provides a ranking of the alternatives, in which higher values determines a better alternative. ANOVA analysis for GRA grade is shown in Table 5. It

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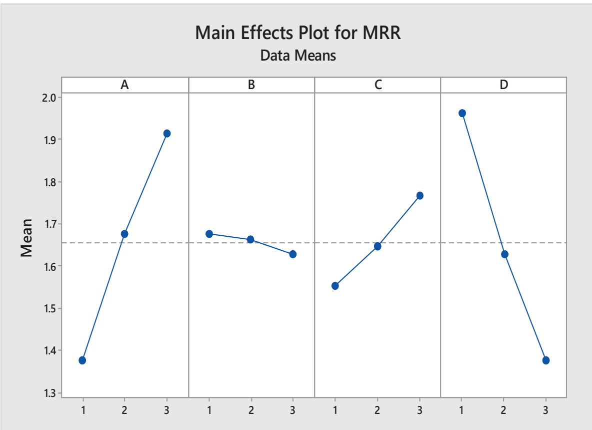
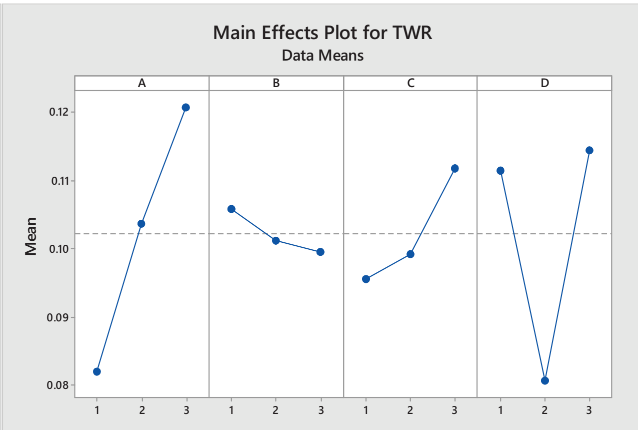
concludes that powder (71.87%) was found to be the most contributing factor for overall performance, followed by the pulse-on time (5.46%) and pulse-off time (3.61%). The rest of the terms were found insignificant.

TABLE II.
TAGUCHI L27 OA EXPERIMENTAL DESIGN AND NORMALIZED VALUES [X*(K)]

Sl. no.	Pulse-on Time, (μs)	Pulse-off Time, (μs)	Current, (A)	Powder	MRR, (mm^3/min)	TWR, (mm^3/min)	MRR [X*(k)]	TWR [X*(k)]
1	30	20	3	CP	1.569	0.0825	0.4028	0.7592
2	30	20	5	AP	1.401	0.0667	0.2895	0.9533
3	30	20	7	*	1.302	0.1084	0.2227	0.4410
4	30	35	3	AP	1.322	0.0629	0.2362	1.0000
5	30	35	5	*	1.105	0.085	0.0897	0.7285
6	30	35	7	CP	1.637	0.0911	0.4487	0.6536
7	30	50	3	*	0.972	0.0883	0.0000	0.6880
8	30	50	5	CP	1.538	0.0809	0.3819	0.7789
9	30	50	7	AP	1.541	0.0734	0.3839	0.8710
10	50	20	3	CP	1.968	0.1156	0.6721	0.3526
11	50	20	5	AP	1.681	0.0841	0.4784	0.7396
12	50	20	7	*	1.519	0.1381	0.3691	0.0762
13	50	35	3	AP	1.583	0.0754	0.4123	0.8464
14	50	35	5	*	1.323	0.1018	0.2368	0.5221
15	50	35	7	CP	2.162	0.1270	0.8030	0.2125
16	50	50	3	*	1.219	0.0975	0.1667	0.5749
17	50	50	5	CP	1.931	0.1103	0.6471	0.4177
18	50	50	7	AP	1.702	0.0842	0.4926	0.7383
19	70	20	3	CP	2.062	0.1194	0.7355	0.3059
20	70	20	5	AP	1.841	0.0948	0.5864	0.6081
21	70	20	7	*	1.742	0.1433	0.5196	0.0123
22	70	35	3	AP	1.729	0.0873	0.5108	0.7002
23	70	35	5	*	1.654	0.1367	0.4602	0.0934
24	70	35	7	CP	2.454	0.1443	1.0000	0.0000
25	70	50	3	*	1.565	0.1315	0.4001	0.1572
26	70	50	5	CP	2.343	0.1324	0.9251	0.1462
27	70	50	7	AP	1.842	0.0971	0.5870	0.5799
[X*(K)] =	Normalized Values for kth experiment							



Figures 2. Effect for MRR



Figures 3. Effect for TWR

TABLE III.
DEVIATION VALUES [ΔXI(K)], GREY RELATIONAL CO-EFFICIENT [ЄI(K)], GREY RELATIONAL GRADE, RANKING

Sl. no.	MRR [$\Delta X_i(k)$]	TWR [$\Delta X_i(k)$]	MRR [$€_i(k)$]	TWR [$€_i(k)$]	GRG [η_j]	Rank
1	0.5972	0.2408	0.4557	0.6749	0.5653	11
2	0.7105	0.0467	0.4131	0.9146	0.6639	3
3	0.7773	0.559	0.3915	0.4721	0.4318	23
4	0.7638	0	0.3956	1.0000	0.6978	1
5	0.9103	0.2715	0.3545	0.6481	0.5013	19
6	0.5513	0.3464	0.4756	0.5907	0.5332	16
7	1	0.312	0.3333	0.6158	0.4746	20
8	0.6181	0.2211	0.4472	0.6934	0.5703	9

9	0.6161	0.129	0.4480	0.7949	0.6215	4
10	0.3279	0.6474	0.6039	0.4358	0.5199	18
11	0.5216	0.2604	0.4894	0.6575	0.5735	8
12	0.6309	0.9238	0.4421	0.3512	0.3967	27
13	0.5877	0.1536	0.4597	0.7650	0.6124	6
14	0.7632	0.4779	0.3958	0.5113	0.4536	22
15	0.197	0.7875	0.7174	0.3883	0.5529	13
16	0.8333	0.4251	0.3750	0.5405	0.4578	21
17	0.3529	0.5823	0.5862	0.4620	0.5241	17
18	0.5074	0.2617	0.4963	0.6564	0.5764	7
19	0.2645	0.6941	0.6540	0.4187	0.5364	15
20	0.4136	0.3919	0.5473	0.5606	0.5540	12
21	0.4804	0.9877	0.5100	0.3361	0.4231	24
22	0.4892	0.2998	0.5055	0.6252	0.5654	10
23	0.5398	0.9066	0.4809	0.3555	0.4182	25
24	0	1	1.0000	0.3333	0.6667	2
25	0.5999	0.8428	0.4546	0.3724	0.4135	26
26	0.0749	0.8538	0.8697	0.3693	0.6195	5
27	0.413	0.4201	0.5476	0.5434	0.5455	14
ΔXI(K)= Deviation values, €I(K)= Grey relational co-efficient						

TABLE IV.
RESPONSE TABLE FOR MEANS

Level	A	B	C	D
1	0.5622	0.5183	0.5381	0.5654
2	0.5186	0.5557	0.5420	0.6012*
3	0.5269	0.5337	0.5275	0.4412
Delta	0.0436	0.0374	0.0145	0.1600
Rank	2	3	4	1

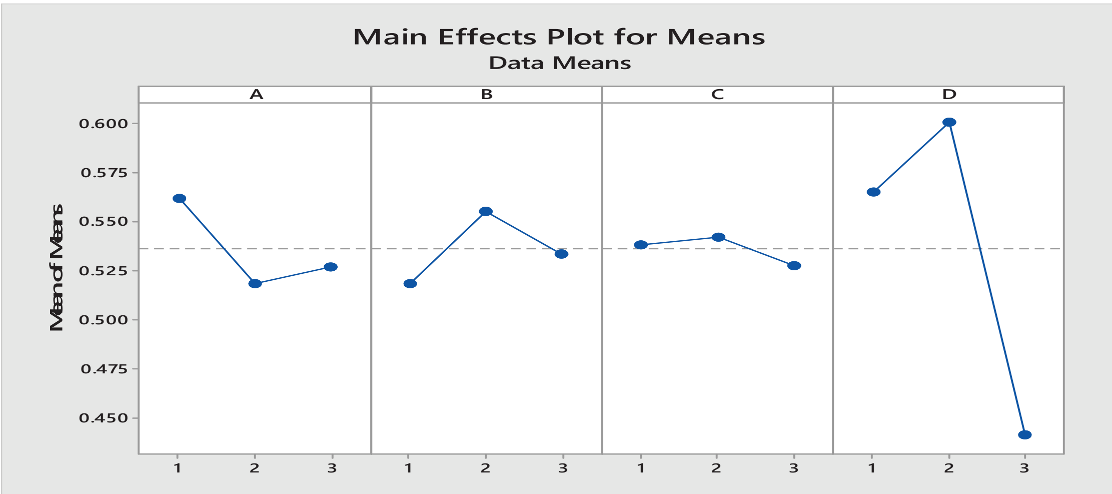


Figure 4. Overall performance based on GRA grade

TABLE V.
ANOVA TABLE FOR GRA METHOD

Factors	DOF	Adj SS	Adj MS	F-Value	P-Value	% of Contribution
T_{ON}	2	0.009642	0.004821	7.32	0.025	5.461033
T_{OFF}	2	0.006372	0.003186	4.84	0.056	3.608971
Current	2	0.001014	0.000507	0.77	0.504	0.574309
Powder	2	0.126890	0.063445	96.31	0.000	71.86792
$T_{ON} \times T_{OFF}$	4	0.000569	0.000142	0.22	0.920	0.32227
T_{ON} × Current	4	0.007148	0.001787	2.71	0.132	4.048482
T_{ON} × Powder	4	0.020969	0.005242	7.96	0.014	11.87642
Error	18	0.003952	0.000659			2.238333
Total	26	0.17656				100

V. Conclusions

Witnessing the increasing application of powder-mixed EDM processes, this study has been conducted to optimize its process parameters. This work investigates results of powder mixed EDM of tungsten carbide by using GRA technique. GRA method has been used to determine the significant factors and the optimum machining conditions to enhance the performance of EDM. Graphite and alumina powders are used in working fluid, whereas graphite powder seems suitable for high MRR. Alumina powder has been found suitable for low TWR. Alumina powder has been found to be the primary governing factor for these response characteristics.

References

[1] Sharma R K, Singh J (2014) "Effect of powder mixed electrical discharge machining (PMEDM) on difficult to machine materials - A systematic literature review", Journal for Manufacturing Science and Production, 14(4), 233–255.

[2] S. K. Sahoo, A. Bara, A.K. Sahu, S.S. Mahapatra, D.S. Kiran, G.S. Teja, E.S. Teja and S.P. Reddy, Analysis and Optimization of Wire EDM Process Parameters by using GRA Methodology; Materials Science Forum, Trans Tech Publications, Scientific.Net, 969 (2019), pp. 678-684.

[3] Kung K Y, Horng J T, Chiang K T (2009) "Material removal rate and electrode wear ratio study on the powder mixed electrical discharge machining of cobalt-bonded tungsten carbide", Int Jour of Adv Manuf Tech, 40(1–2): 95–104.

[4] Khundrakpam, N. S., Brar, G. S., & Deepak, D. (2016). Experimental investigation on EDM processes by tool rotating speed. *Bonfring Int. J. Ind. Eng. Manag. Sci*, *6*(4), 171-173.

[5] Kansal H K, Singh S, Kumar P (2005) "Parametric optimization of powder mixed electrical discharge machining by response surface methodology", Journal of Materials Processing Technology, 169, 427–436.

[6] Sharma R K, Singh J (2016) "Determination of multi-performance characteristics for powder mixed electric discharge machining of tungsten carbide alloy", Proc IMechE Part B: J Engineering Manufacture, 230 (2), 303–312.

[7] Zhao W S, Meng Q G, Wang Z L (2002) "The application of research on powder mixed EDM in rough machining", Journal of Material Processing Technology, 129, 30-33.

[8] Kansal H K, Singh S, Kumar P (2007) "Technology and research developments in powder mixed electric discharge machining", Journal of Materials Processing Technology, 184, 32–41.

[9] A.K. Sahu, P.P. Mohanty, S.K Sahoo, Electro discharge machining of Ti-alloy (Ti6Al4V) and 316LStainless Steel and Optimization of process parameters by Grey relational analysis (GRA) method, Advances in 3D Printing & Additive Manufacturing Technologies, Springer, 2017, pp. 65-78.

[10] Mahdavinejad R.A., Mahdavinejad A. ED machining of WC–Co. Journal of Materials Processing Technology, 2005, 162–163, 637–643.

[11] Pragya Shandilya, Arun Kumar Rouniyar and D Saikiran, Multi-objective parametric optimization on machining of Inconel-825 using wire electrical discharge machining, J Mechanical Engineering Science, SAGE, 234(2020), pp. 4056–4068.