International Journal of Current Trends in Engineering & Technology
ISSN: 2395-3152
Volume: 03, Issue: 06 (NOVEMBER - DECEMBER, 2017)

Experimental and Numerical Simulation of Tungsten Carbide Composite Alloy Using Grey Relational Analysis

Rahul Nadda, Amandeep, Raj Kumar
School of Mechanical and Civil Engineering
Shoolini University, Bajhol (Solan), (H.P.), India
[1]rahulnadda74@gmail.com, [2]amandelthi7@gmail.com, [3]errajap@gmail.com

Abstract— *The aim of this paper is to find out the optimum set of process parameter on electrical discharge machining (EDM) during the machining of tungsten carbide. For the experimental study four input parameters viz. pulse-on time, pulse-off time, pulse current and voltage are selected to study the enhancement in multi-performance characteristics with Taguchi L9 orthogonal array model. Theoretical calculation of results achieved by grey relational grade technique depicts that the projected method proved helpful to optimize the material removal rate (MRR), (TWR) and (SR). A t-test is employed to determine significant control parameters. From the above experimental and logical responses, it is obtained that the pulse-off time; pulse current and voltage are major effecting factors in EDM of cobalt bonded tungsten carbide.*

Keyword— Grey relational analysis, L9 array, Taguchi approach, t-test, material removal rate, surface roughness.

I. INTRODUCTION

Electro discharge machining is a method to facilitate the removal of metal through the action of an electrical discharge for small period and large current concentration between the electrode and specimen [1]. In order to create parts of the fundamental condition a suitable machining process is to be selected. Among the range of non-conventional machining methods, EDM is the most broadly used and effectively applied for hard to machine materials, produce complex shapes [2-4]. The EDM method is most widely used in die making, mould making, surgical components and aerospace material. Die-sinking EDM is a non-conventional operational method in which the tool electrodes and specimen is submerged in dielectric fluid. The EDM method allows the machining of each type of material which is good conductor of electricity. EDM is used to machine the tough, thermal resistance and complicated shapes of materials. EDM eliminates electrically conductive Objects by means of repetitive and quick spark discharges resulting from confined explosion of a dielectric fluid and this explosion is formed by applying voltage between electrode and specimen [5-6]. The EDM method consists of normal tool which is simply used to eliminate strong and tough material by evaporation and melting. Hence experimental functioning on electrical EDM for hard to manufacture materials is tempted significant attraction. Some of the research has occupied a sequence of operations to find out EDM workability and functioning for its appliance that is hard to machining of material. The utilization of this method by variant industry has increased in current years due to its correctness for cutting complex shapes such as well micro-holes, slots and mould tool which are prepared in mainly hard materials [7-9]. Lin et al. [10] studied the influence of electrical discharge energy on machining description of two variant types of cemented tungsten carbides having P10 and K10 grades. They found that there exists a particular series of machining factor within which the method is steady, and that extremely long or short pulse period cause process unsteadiness. Lee and Li [11] investigated the influence of EDM parameters on surface quality of a type of tungsten carbide (WC). They revealed that SR and MRR of specimen are extra quantitative way. The influence of variant electrode materials on the well-finish type of R-C die-sinking micro-EDM of WC was investigated by Jahan et al. [12] and they found that the resultant criteria in a comparative way was provided as optimal alternative for finish in die-sinking micro-EDM of WC and moreover the tool electrode gives without fault and smoother nano face with the smallest and respectively. Puertas and Luis [13] investigated the performance of two extremely realistic conductive ceramics in industry, WC-Co and, under variant die sinking EDM conditions. Pandit and Rajurkar [14] prepared a thermal design depend upon data dependent system technique to study the characteristics and calculate the MRR of cemented carbide. However evaluate their conclusion with those available by the CIRP. They define the insignificance in comparing the influence of operational parameters on the progression efficiency which is suitable to the stochastic process character, difficult composition and structure of the work piece material. A non-conquered cataloguing genetic algorithm was applied by Kanagarajan et al. [15] to obtain a Pareto best sequence of input variables in a trade off approach in which the choice of the best machining setting based on elements. Pecas and Henriques [16] analyzed the existence of powder element in dielectric fluid and assured that the concentrations of powder produce situations appropriate to attain better surface quality in the machined region. Wu et al. [17] performed an experiment to study the influence of Al powder in the dielectric liquid on during the machining of SKD61 specimen by copper tool electrode. They observed that value of SR has been enhanced up to 60% as compared to electrical discharge machined under pure dielectric fluid. Bhattacharya et al. [18] investigated the surface classification and material movement at some stage in surface modification of die steel through tungsten, silicon and graphite powder in EDM method and analyzed the two outcomes i.e. SR and micro hardness. Assarzadeh and Ghoreishi [19] investigated the progression factors in EDM of WC-Co composite with response surface methodology (RSM) and analyze the conclusions for output response i.e. TWR, MRR and SR respectively. Banerjee et al. [20] used face-centered central composite model to gather experimental information and RSM to design and analyze the dispensation parameters occupied in electrical discharge machining of (WC-) cemented carbide. They revealed that adequate superheating of specimen materials and sub face boiling is necessary for capable MRR. Pandey and Jilani [21] investigated the effects of deviations in pulse period on the EDM description of three different types of WCs with a variety of cobalt contents. They found that the existence of cobalt has a considerable effect on the machining performance of carbide in such a manner that a superior cobalt percentage results an additional inclination to surface cracking and defects. From the overall literature review, it is found that a lot of work has been assumed by different authors to examine the variety of performance characteristics, but a little amount of work which deals [22-24] with managing the demerits of uncertainty related with the unsure, multi- input and separate information with the grey approach is reported and a t-test was carried out on all designed data. A multipurpose optimization approach depend on the utilization of desirability function model was then used to discover best input factors setting in variant machining system yielding the maximum feasible MRR and minimum feasible TWR in a cooperative manner simultaneously subject to a specific limit on SR to specify machining system. Finally, verification of experiments was also performed to confirm the realness and validity of achieved optimal parametric setting. In the present study author prepared five steps as depicted in Fig. 1 depend upon grey relational method. An application of EDM of cobalt bonded tungsten carbide (85%WC-15%Co) is employed to study the multi-response description i.e. TWR, MRR and SR, by a specific arrangement of controlled setting in the Taguchi L9 orthogonal array parameter design. To the best of author's knowledge the open literature does not consists a related type of investigation on "Experimental and numerical simulation of tungsten carbide composite alloy using grey relational analysis."

II. FRAMEWORK OF RESEARCH METHOD

The structure depicted in Fig.1 shows the information of research method implemented in the study. The steps drawn in the framework are explained briefly as follow:

1. First of all the most effective parameters with their levels are selected to conduct the experiments
2. The Taguchi L9 orthogonal array (OA) is modeled to perform the experimental work.
3. An overall of 9 experimental run are carried out on the cobalt bonded WC (85% WC-15% Co) through four input factors. Grey relational analysis is calculated for the values of MRR, TWR and SR, and grey relational grade as an output result is achieved. Moreover, best parameters are picked by grey relational result table.
4. The theoretical calculations are made to confirm the total enhancement with grey approach.
5. To find out the contribution of main significant parameters, t- testing has been made.

III. MACHINE TOOL, SPECIMEN, ELECTRODE AND DIELECTRIC FLUID MATERIALS

In PRESENT study the experiments were performed on ZNC 5030 die-sinking EDM manufactured by Ratnaparkhi electronics Pvt. Ltd. India. The photographic view of machine and operational run is shown in Figs. 2 and 3. It is capable to supply maximum pulse current up to 50A.

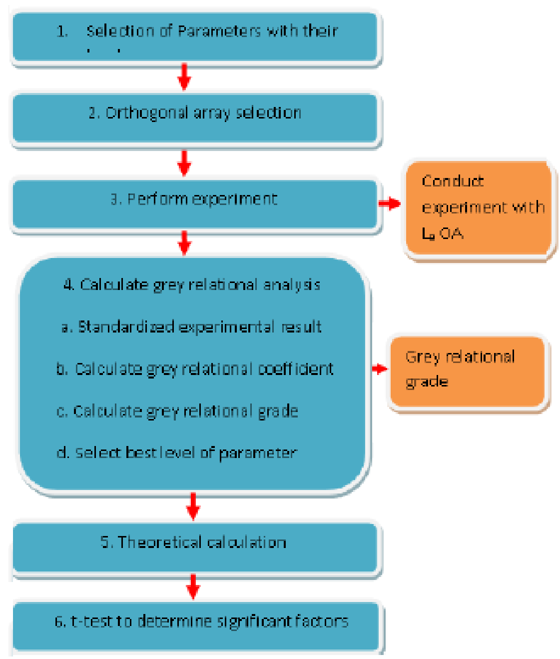

Fig.1. Structure of grey relational grade

The cobalt bonded WC composite, type GT 30 grade, having approximately 85% WC and 15% Co, available in square shape, with 100mm length 50mm width 12mm thickness has been selected as specimen material. The chemical composition and mechanical properties of specimen are shown in Table1. The selected specimen was of a perfect grain structure and mostly used in manufacturing non-ferrous metals, cutting tools and drawing dies. The copper tool, available in cylindrical shape, with 15.9mm diameter and 20.4mm length has been selected as tool electrode material. The EDM oil was employed as a dielectric fluid and driven out as impulse side flushing with a nozzle in the specimen and nozzle gap.

IV. EDM METHOD

EDM is also known as non-conventional machining method during this procedure, a voltage of 80-320V is employed between the specimen and the tool electrode. Spark gap which is of 25-50mm is crammed up by means of the preservative particles suspended during flushing. Under the effect of large potential strength, the particle become excited, get accelerated, travel in zigzag manner and can operate as conductors [25].

Fig.2. Photographic view of ZNC 5030 die-sinking EDM

Fig.3. Photographic view of experimental setup

Due to the generation of bridging effect the insulating intensity and gap voltage of dielectric liquid reduced. A series of discharge generated between the electrode and the specimen due to the short-circuit phenomenon. If the frequency of discharging current, increases the rapid erosion of material occurs from the specimen. The minimum debris can result in arcing due to the insufficient specific supply with extremely place resolution. Moreover, too much concentration can raise spark attention that is, arcing, tends to unsteady and inefficient development. A transparent container having 400L capacity, known as machining tank, is located in the work chamber of EDM, and the machining is carried out in the container. For superior circulation of dielectric fluid and mixing of solute and solvent a stirrer is employed in the container. The schematic diagram for EDM is depicted in Fig.4

Table (1) Variables for EDM method

Working conditions	Details
Work piece	Tungsten carbide – Cobalt composite (85% WC and 15% Co), Square piece of 100 mm length × 50mm width ×12 mm thickness, Compressive strength: 3100 N/mm^2, Young's Modulus: 411Gpa, Specific gravity of WC: 14 g/cm^3, Melting point of WC: 3422 ºC, Transverse rapture strength: 2800 N/mm^2, Hardness: 1200 HVN, Density: 15.6 g/cm^3
Electrode	Electrolytic copper, Cylindrical rod of 15.9mm diameter and 20.4mm length, Hardness: 8.6 HB Melting point: 1085 ºC, Electrical resistivity: 105 µΩ cm, Density: 8.7 g/cm^3
Polarity	Work piece +ve, electrode –ve.
Machining	15 min

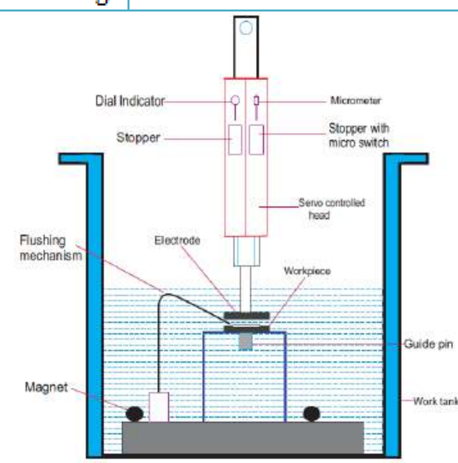

Fig.4. Schematic diagram of EDM setup

Table (2) Controllable factors with their conditions and levels for operational run

Sr. No.	Experimental factors	Symbol	Factors Level		
			Level 1	Level 2	Level 3
1.	Pulse-on time	(µs)	25	90	250
2.	Pulse-off time	(µs)	40	63	67
3.	Pulse current	(A)	4	8	12
4.	Voltage	(V)	50	55	60
5.	Polarity	Work piece +ve, Electrode –ve.			
6.	Dielectric fluid	EDM oil			

V.SELECTION OF MACHINING PARAMETERS AND DESIGN OF EXPERIMENTS

The four convenient input parameters viz. pulse-on time, pulse current, pulse-off time and voltage were selected to calculate the process performance in terms of TWR, MRR and SR. The design of controlled process parameters with their levels are shown in Table 2. The present study includes L9 OA which consists of 4 factors with 3 levels as depicted in Table 2. These OA propose specific composition of partial functions with respect to the effecting factors and their different levels. Overall 9 operations are carried out as per OA and the response of every operational run is shown in Table 3. The responses achieved are then transformed into ratios which are significant and insignificant parameters in a physical statement.

VI. RESPONSE MEASUREMENT

6.1 Material removal rate

Material removal rate is calibrated as the relation of weight of specimen before machining and weight of specimen after machining to the product of machining duration and density of material. The MRR is measured for every cutting situation (mm3/min), by determining the average quantity of material separated and the machining period. The MRR can be calculated by using the equation (1):

$$MRR = \frac{W_{bm} - W_{am}}{t \times \rho} \qquad (1)$$

Where, ""Wbm" is the specimen weight before machining, ""Wam" is the specimen weight after machining, "ρ" is the density of the specimen and "t" is the machining period.

6.2 Tool Wear Rate

Tool wear rate is obtained as the ratio of difference of weight of tool electrode before machining and weight of tool electrode after machining to the machining period. Tool wear rate is also calibrated for every cutting condition, by calculating the average quantity of material removed from electrode and machining period. The TWR can be calculated by using the equation (2):

$$TWR = \frac{W_{tb} - W_{ta}}{t} \qquad (2)$$

Where, "Wtb" is the weight of the tool electrode before machining, "Wta" is the weight of the tool electrode after machining and "t" is the machining period.

6.3 Surface Roughness

The SR is calculated by the means of arithmetic mean, it is defined as the arithmetic normal SR of the variation of the roughness profile from the central line beside the measurement [25]. The SR can be provided by using equation (3).

$$R_a = \frac{1}{L}\int_0^L |h(x)dx| \qquad (3)$$

Here is value of arithmetic average; L is estimated length; h(x) is roughness profile. The SR of specimen is determined by precise Talysurf profilometer. The surface roughness is obtained by average centre line method. A diamond stylus with a vertical length of 110 mm and tip radius of 25μm is used to find out the SR.

VII. TAGUCHI BASIC CONCEPTS

The identification of significant factors is made by using standard Taguchi suggested selection process. To reduce the influence of uncertainty, due to the effect of noise and out of control parameters, on the experimental output response of TWR, MRR and SR, the experiments were performed nine times and the standard values of every response were consequently used to analyze the results. The optimization of examined values was obtained by evaluating the S/N ratio, depend on Taguchi approach. The S/N ratio (η_L), for Higher is better (HB) quality criteria is used to find out the MRR and can be provided as follow:

$$\eta_L = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \qquad (4)$$

Also, the S/N ratio (η_S), for Lower is better (LB) quality criteria is used to find out the TWR and SR respectively, and can be defined as follow:

$$\eta_s = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \qquad (5)$$

Here, is the experimental value; n represents the number of trials; and are the calibrated values of S/N ratio. With the help of equation (4) and (5), the S/N ratio values are calculated for TWR, MRR and SR to categorize the range of main significant factors depicted in Table 3.

Table (3) Experimental model for L9 Taguchi approach

Run	T_{on}	T_{off}	I_p	V	MRR	TWR	SR
	μs	μs	A	V	mm^3/min	gm/min	μm
1	25	67	4	60	0.0196	0.0028	4.8
2	25	40	12	55	0.0415	0.0009	3.4
3	25	63	8	50	0.0275	0.0049	3.8
4	90	40	8	60	0.0396	0.002	4
5	90	67	12	50	0.0242	0.0008	5.2
6	90	63	4	55	0.0545	0.0031	3.5
7	250	63	8	50	0.0334	0.0013	7.4
8	250	67	12	55	0.0615	0.0003	2.6
9	250	40	4	60	0.0512	0.004	6.1

VIII. GREY RELATIONAL ANALYSIS

As stated beyond, the conventional Taguchi process is not appropriate for optimization of multi-purpose optimization difficulties. To conquer this problem the grey relational analysis (GRA), is employed to optimize multipurpose problems. In GRA, investigational information is first standardized in the range between 0 and 1, and hence matrix produced is known as grey relational generation matrix. The grey relational coefficient (GRC) is calibrated from the standardized matrix to signify the relationship between the predicted and actual experimental results. Then the total grey relational grade (GRG) is calculated by averaging the GRC for the particular outputs. Hence, the multi-objective difficulties are changed into single output optimization problem among total GRG as a goal function. The last stage is to make the t- testing and calculates the best GRG. In the current study the GRG is used to find out the best combination of the higher MRR and minimum TWR and SR respectively. The first stage is to standardize the experimental information in the range of 0-1 by applying criteria of HB for MRR and LB for TWR and SR, respectively. The LB and HB criteria are provided by equations (6) and (7) as follow:

$$A_i^*(k) = \frac{\max A_i^0(k) - A_i^0(k)}{\max A_i^0(k) - \min A_i^0(k)} \qquad (6)$$

$$A_i^*(k) = \frac{A_i^*(k) - \min A_i^0(k)}{\max A_i^0(k) - \min A_i^0(k)} \qquad (7)$$

Here, $A_i^*(K)$ is value after GRG; A^0 is the required value; max$A_i^0(K)$ is the maximum value of$A_i^0(K)$; min$A_i^0(K)$ is the minimum value of; $A_i^0(K)$ i represent the experimental run and k represents the responses.

8.1 Grey Relational Coefficient

The next stage is to calculate the GRC. The GRC is calibrated to express the correlation between the optimal and actual standardized experimental results that can be determined as follow in equation (8).

$$\psi_i(K) = \frac{\Delta_{min}(K) + \varsigma \times \Delta_{max}}{\Delta_{oi}(k) + \varsigma \times \Delta_{max}} \qquad (8)$$

Here,$\Delta_{0i}(k)$ is the variation progression of the reference series$A_0^*(K)$ and the compressibility series of $A_i^*(K)$, i.e.

$$\Delta_{max} = \max_{\forall j \in i} \max_{\forall k} \|x_0^*(k) - x_i^*(k)\| \qquad (9)$$

$$\Delta_{0i}(k) = \|x_0^*(k) - x_i^*(k)\| \qquad (10)$$

Here, ς is the distinguishing and identification coefficient; normally $\varsigma \in [0,1] \times \varsigma$ is used for experiment and in this study is also used as 0.5.The coefficient ψ_i lies among 0 and 1 which extend or smalls the rank of grey relation coefficient.

8.2 Grey Relational Grade

In GRA, the GRG is employed to depict the correlation between the series. As the two series are equal, then the GRG value is identical to 1. The GRG also specify that the comparability series can apply above the reference series. The GRG is calculated by averaging the GRC as provided by equation (12):

$$\gamma_i(k) = \frac{1}{m}\sum_{k=1}^{m} \psi_i(K) \qquad (12)$$

Here, $\gamma_i(k)$ is GRG for ith operation; m in the number of outputs.

IX. RESULTS AND DISCUSSION

9.1 GRA of Experimental Data

The L9 OA provides the mine experimental values for MRR, TWR and SR shown in Table 3 which is standardized in the level of 0-1 by employing equation (6) and (7).

Table (4) Normalized values of criterion for every experimental cycle

	Normalized values of Criteria		
Experiment run	MRR	TWR	SR
1	1	0.45	0.55
2	0.52	1	0.83
3	0.19	0	0.74
4	0.48	0.64	0.71
5	0.11	0.9	0.47
6	0.83	0.4	0.81
7	0.33	0.79	0
8	0	0.86	1
9	1	0.45	0.55

To state the correlation among the predicted and actual experimental information, the GRC are calculated by employing equation (8). The standardized values of the output response i.e. MRR, TWR and SR along with GRC and GRG are presented in Table 4. The GRG is determined with sum of both values of GRC and after that divided by overall number of responses which are obtained, as depicted in equation (12). In this stage the various GRG achieved for every output are changed into particular GRG value. The rank of every operational run, GRG values and S/N ratios are presented in Table 4 and in Figure 4. The GRG values are in the range of 0 to 1and the ranking is well organized with HB characteristics. The results show that the 8th operational run provided the higher value of GRG. Hence, the 8th experiment provides the optimal performance description between all the experiments. The average of GRG S/N ratio for every level of MRR, TWR and SR is depicted in Table 5 and Fig.5. The S/N ratio is used by Taguchi approach for determining the difference of the operational design. The maximum S/N ratio provides the optimal results. The Fig. 6 shows that maximum S/N ratio of GRG is achieved for 8th operational run and the best factors arrangement is obtained at pulse-on time of 250µs,

International Journal of Current Trends in Engineering & Technology
ISSN: 2395-3152
Volume: 03, Issue: 06 (NOVEMBER - DECEMBER, 2017)

pulse-off time of 67μs, pulse current of 12A and voltage of 55v respectively and the similar result. The average output values of GRG in S/N ratio form are presented in Table 5.

Table (5) Grey relational coefficient of criterion

	GRG coefficient criteria		
Experiment Run	MRR	TWR	SR
1	1	0.475	0.52
2	0.333	0.783	1
3	0.381	0.333	0.66
4	0.489	0.581	0.63
5	0.359	0.827	0.48
6	0.749	0.453	0.73
7	0.427	0.703	0.33
8	0.512	1	0.75
9	1	0.475	0.52

Table (6) Grey relational grade, S/N ratio and rank of experimental run

	GRG, S/N ratio with its Rank		
Experiment run	Grade	S/N Ratio	Rank
1	0.667	-3.51748	3
2	0.705	-3.03622	2
3	0.459	-6.76375	8
4	0.567	-4.92834	6
5	0.556	-5.0985	7
6	0.643	-3.83578	5
7	0.488	-6.2316	9
8	0.753	-2.4641	1
9	0.666	-3.53052	4

The optimal result for each parameter is depicted in bold form. It presented that if the control parameter, i.e. pulse-on time is sustained at level-3 (250μs), which is -4.26611; pulse-off time is sustained at level-3 (67μs), i.e. -3.88407; pulse current is sustained at level-3 (12A), i.e. -3.53294 and the voltage are sustained at level-2 (55V), i.e. -3.11203, than the best response is obtained. The higher-lower column presented in Table 5 shows that the Voltage is major significant parameter from the four input factors. The Table 4 shows the GRG values for all the 9 operational run with their ranking. Maximum value obtains higher rank. The experiment 9 provided the maximum value which is, 0.753. It reveals that the experiment eight has best relationship of all the factors such as pulse-off time, pulse current, pulse-on time and voltage to generate maximum MRR and minimum TWR and SR.

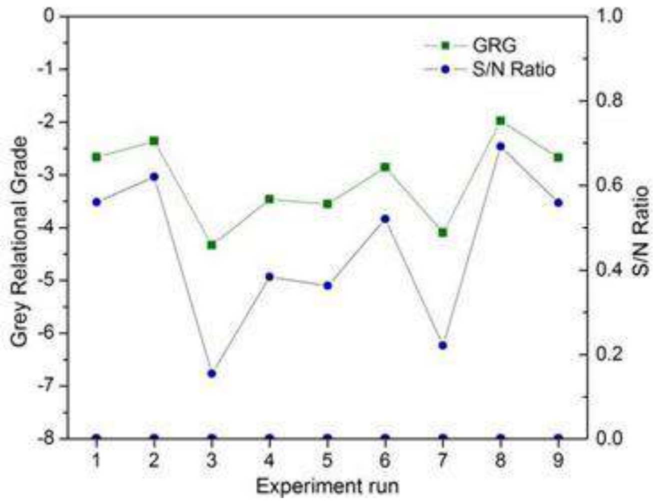

Fig.4. Grey relational grade with its S/N ratio

Table (7) Output table for GRG S/N ratio

Sr. No	Operational Parameters	Symbol	Levels			Highest - Lowest
			Level 1	Level 2	Level 3	
1	Pulse-on time	μs	-4.2484	-4.6207	**-4.2661**	0.37243
2	Pulse-off time	μs	-3.641	-5.61038	**-3.8841**	1.9694
3	Pulse current	A	-3.6279	-5.97456	**-3.5329**	2.44162
4	Voltage	V	-6.0313	**-3.11203**	-3.9921	2.91925

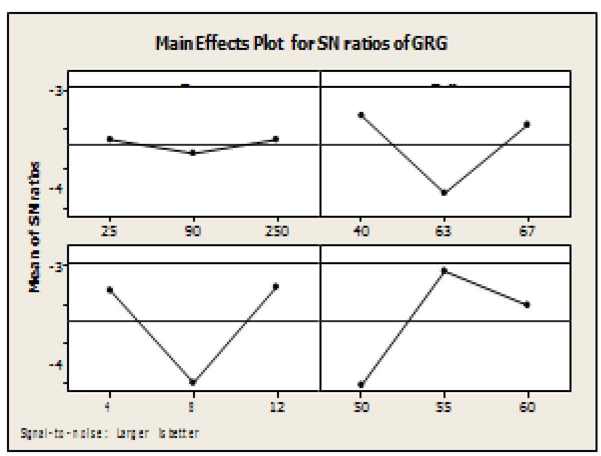

Fig.5. Main effects plot for S/N ratio of GRG

9.2 Theoretical calculation of GRG

From the output table for GRG which is Table 6 the best machining parameter set is achieved for EDM of cobalt bonded tungsten carbide specimen. After discovering the best parameters relationship, it is essential to

International Journal of Current Trends in Engineering & Technology
ISSN: 2395-3152
Volume: 03, Issue: 06 (NOVEMBER - DECEMBER, 2017)

calculate the GRG theoretically. The theoretical calculation of GRG is determined by employing the equation (13) as follow [23]:

$$\hat{\gamma} = \gamma_m + \sum_{j=1}^{q} [\gamma_j - \gamma_m] \qquad (13)$$

Here q is the total number of effecting factors; is GRG mean at best levels; is the GRG average values. Table 6 presents the initial and experimental result values. In Table 6, A_1, B_2, C_1, D_3 are selected as initial machining factors and A_3, B_1, C_1, D3 are selected as best machining factors. It is observed that the MRR in the initial set of levels (A_1, B_2, C_1, D_3) rises from 0.0196 – 0.0615, TWR reduced from 0.00284 – 0.00026 and SR reduced from 4.78 – 2.58 and moreover the GRG is also enhanced from 0.667 – 0.753, which is 8.6% for the best machining factors. The overall results stated that the GRA might be helpful for optimizing the many performances in EDM of tungsten carbide.

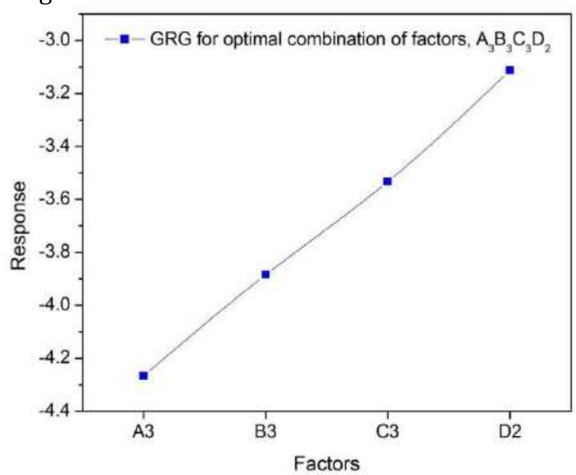

Fig.6. Best combination of control parameters for GRG

The bold value indicates the significant results optimal levels of factors are: pulse-on time (level3); pulse-off time (level 3); pulse current (level 3); voltage (level 2).

Table (8) Results of confirmation experiments

Experimental Parameter	Initial factors	Expected	Verification Experiments
MRR	0.0196	-	0.0615
TWR	0.00284	-	0.00026
SR	4.78	-	2.58
	0.667	0.796	0.753

9.3 T-test of responses

H_a shows that there is no significant relationship between pulse-on time, pulse-off time, pulse current and voltage. In other words pulse-on time, pulse-off time, pulse current and voltage are independent to each other. H_a reveals that there are some significant factors such as pulse-off time, pulse current and voltage which mean that these input parameters are dependent to each other. Table 7 shows that the values of input parameters such as pulse-off time, pulse current and voltage are significant at 95% level of significance because value of p is less than 0.05 it means that the larger amount of discharge energy exists at the machining gap due the high pulse current and voltage. However the pulse-on time is not significant because the value of input parameter is greater than 0.05.Table 8 shows that the pulse-off time – pulse current and pulse current - voltage is significant at 95% level of significance because the value of p is less than 0.05 that means these input parameters are highly dependent on each other for geometric factors and effective machining in EDM.

Table (9) one sample t-test of input factors

One Samples t Test	DF	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
Pulse-on time	8	121.67	100.281	33.427	3.64	0.007
Pulse-off time	8	56.67	12.619	4.206	13.47	.000*
Pulse Current	8	8	3.464	1.155	6.928	.000*
Voltage	8	55	4.33	1.443	38.11	.000*

The values marked with star presents the significant results of input parameters.

Table (10) Paired samples t- test of input factors

Paired Sample Test	DF	Mean	Std. Deviation	Std. Error Mean	t	Sig. 2-tailed
T_{on} - T_{off}	8	65	101.072	33.691	1.929	0.09
T_{on} - I_p	8	6	100.341	33.447	3.398	0.009
T_{on} – V	8	66.7	100.374	33.458	1.993	0.081
T_{off} - I_p	8	48.7	12.933	4.311	11.28	.000*
T_{off} - V	8	1.66	15.346	5.115	0.326	0.753
I_p – V	8	-47	6.764	2.255	-20.84	.000*

The values marked with star presents the significant results of input parameters.

CONCLUSION

In the present research the influence of different machining parameter i.e. pulse-on time, pulse-off time, pulse current and voltage on variant response parameters like MRR, TWR and SR are studied. A round shape copper tool is used as electrode to conduct experiment on cobalt bonded tungsten carbide specimen (WC 85% and Co 15%), the TWR, MRR and SR is then analyzed and optimized. The following conclusions can be drawn from the current work: The major objective of current investigation was to provide a framework that not only assists to achieve best combinations of control parameters but also handle the uncertainty constituents related to many input data. The best set for response parameters, which is MRR, TWR and SR were achieved. The experimental study presented that the 8^{th} experimental run gives the maximum value of GRG by optimal setting of input factors $A_3B_3C_3D_2$, i.e. pulse-on time (250), pulse-off time (67), pulse current (12A) and voltage of (55V). T-test shows that the pulse-off time, pulse current and voltage were contributing and significant factors of obtaining higher MRR and minimum TWR and SR in EDM of 85% WC and 15% Co. The experimental confirmation results show the 8.6% enhancement in grey relational grade values. In summary, this research work was taken up with the objective which presents the effect of variant machining parameters such as pulse-on time, pulse-off time, pulse current and voltage on different responses of EDM i.e. MRR, TWR and SR. The GRG and t-test has been used to optimize and determine the significant control parameters. It was found that at the 8th experiment with the optimal setting of parameters a higher GRG value achieved. Moreover a percentage enhancement of 8.6% was achieved in GRG.

ACKNOWLEDGMENT

The authors would like to thank the publishers, researchers for making their resources available and teachers for their guidance. We thank the university authority for providing the required infrastructure and technical support. Finally, we extend our heartfelt gratitude to friends and family members.

REFERENCE

[1]. Thomson P.F., "Surface in electro discharge machining"; Material Science Technology, 5:1153-1157, 1989.
[2]. Koening W., Komanduri R., "Tokanshoff H.K., Machining of hard metals", Annals CIRP 33 (2):417-427, 1984.
[3]. Snoeys R., Staelens F., Dekeseve W., "Current trends in non-conventional material removal processes", Annals CIRP 35 (2):467-480, 1986.
[4]. Gray F., Benedict, "Non-traditional manufacturing process", Marcel Decker, New York, 1987.
[5]. Bud Guitrau E., "The EDM Handbook, Hanser Gardner Publications, Cincinnati", OH. Chapter I, 1997.
[6]. Chincholle L., "New theory to define the mechanism of metal-cutting EDM", Mech. Mat. Electr. (301-302):17-22, 1975.
[7]. Roche A., Livshits A.L., "Machining and EDM guide by electrochemistry", Edition CETIM,France.1980.
[8]. Wijers J.L.C., "New development in EDM", EDM Digest (January/February) 20-26, 1984.
[9]. Hocheng H., Lei W.T., Hsu H.S., "Preliminary study of material removal in electrical-discharge machining of Sic/Al", Journal of Material Processing and Technology, 63 (1-3):813-818, 1997.
[10]. Lin Y.C., Chen Y.F., Lin C.T., Tzeng H.Y., "Electrical discharge machining characteristics associated with electrical discharge energy on machining of cemented tungsten carbide", Materials and Manufacturing processes, 23, PP, 391-399.
[11]. Lee S.H., Li X.P., "Study of the effect of machining parameters on the machining characteristics in electrical discharge machining of tungsten carbide", Journal of Material Process Technology, 115, PP. 344-358.
[12]. Jahan M.P., Wong Y.S., Rahman M., "A study on the Fine-finish die-sinking micro-EDM of tungsten carbide using different electrode materials", Journal of Material Process Technology, 209, PP. 3956- 3967.
[13]. Puertas I., Luis C.J., "Optimization of EDM conditions in the manufacturing process of B4C and WC-Co conductive ceramics", International Journal of Advance Manufacturing Technology, 59 (5-8),PP.575-582.
[14]. Pandit S.M., Rajurkar K.P., "Analysis of electrical discharge machining of cemented carbides", Annals of the CIRP, 30, PP. 111-116.
[15]. Kanagarajan D., Karthikeyan R., Palani kumar K., Sivaraj P., "Influence of process parameter on electric discharge machining of WC/ 30%Co composite", Proceeding ImechE, Part B: J. Engineering Manufacture, 222,PP. 807-815.
[16]. Pecas P. Henriques E., "Effects of powder concentration and dielectric flow in the surface morphology in electrical discharge machining with powder-mixed dielectric", International Journal of Advance Manufacturing Technology, 37:30-33, 2002.
[17]. Wu K.L., Yan B.H., Huang F.Y., "Improvement of surface finish on SKD steel using electro-discharge machining with Al and surfactant added dielectric", International Journal of Machine Tool Manufacturing, 45:1195-1201, 2005.
[18]. Meena V.K., Azad M.S., "Grey relational analysis of micro-EDM machining of Ti-6Al-4V alloy", Material Manufacturing Process, 27:973-977, 2012.
[19]. AssarZadeh S., Ghoreishi M., "Statical modelling and optimization of process parameters in electro discharge machining of cobalt bonded tungsten carbide", Proceeding CIRP, 6:464-469, 2013.
[20]. Banerjee S., Mahapatro D., Dubey S., "Some study on electrical discharge machining of cemented carbide", International Journal of Advanced Manufacturing Technology., 43:1177-1188, 2009.
[21]. Pandey P.C., Jilani S.T., "Electrical machining characteristics of cemented carbides", Wear, 116:77-88, 1987.
[22]. Liu S.F., Lin Y., "An Introduction to grey system: foundations, methodology and applications", Grove City, PA: IIGSS Academic Publisher, 1993.
[23]. Narender S.P., Raghukandan K., Pai B.C., "Optimization by grey relational analysis of EDM parameters on machining Al-10% SiCp composites", Journal of Material Processing Technology, 155-156:1658-1661, 2004.
[24]. Chenthil Jegan T.M., Dev M. A., Ravindran D, "Determination of electro discharge machining parameters in AISI 202 stainless steel using grey relational analysis", Proceeding Engineering 38:4005-4012, 2012.

[25]. Kumar A., Maheshwari S., Sharma C., "Research developments in additives mixed electrical discharge machining: a state of art review", Material Manufacturing Process, 25:1166-1180, 2010.
[26]. Kansal H.K., Singh S., Kumar P., "Technology and research development in powder mixed electric discharge machining", Journal of Material Processing Technology, 187:32-41, 2007.

INDEX

Nomenclature	
A	Ampere
Co	Cobalt
CIRP	Colombo institute of psychology
DOE	Design of experiment
DF	Degree of freedom
EDM	Electrical discharge machining
GRA	Grey relational analysis
GRC	Grey relational coefficient
GRG	Grey relational grade.
I_p	Pulse current
LB	Larger is best
MRR	Material removal rate
NB	Nominal is best
OA	Orthogonal array
RSM	Response surface methodology
SR	Surface roughness
SB	Smaller is best
S/N	Signal to noise ratio
T_{on}	Pulse-on time
T_{off}	Pulse-off time
TWR	Tool wear rate
V	Voltage
WC	Tungsten carbide

AUTHOR'S PROFILE

Rahul Nadda , Obtained his Bachelor of Engineering degree in Mechanical Engineering from the Shoolini University Solan, India. He obtained his Master of Engineering in Production Technology from Shoolini University, India. He has published about 10 research papers in International Journals/Conferences of high repute. He is currently working as a PhD Scholar at Shoolini University (Solan), India.

Amandeep, Obtained his Bachelor of Engineering degree in Mechanical Engineering from the Shoolini University Solan, India. He pursued his Master of Engineering in Production Technology from Shoolini University, India. He has published about 1 research papers in International Conferences of high repute.

Dr. Raj Kumar , Obtained his Bachelor of Engineering degree in Mechanical Engineering from the North Maharashtra University Jalgaon (M.S), India. He obtained his Master of Engineering in Manufacturing Technology from Panjab University Chandigarh, India. He received his Doctor of philosophy from Shoolini University, Solan (H.P), and India. He has published about 20 research papers in International Journals/Conferences of high repute. He is currently working as an Assistant Professor at Shoolini University (Solan), India.