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Research Article

Study of Various Parameters on Automatic EDM for Machining of HSTR Alloys

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ABSTRACT

Nowadays we are looking forward to the needs of too much, such as material use in the medical, aerospace-industries & military industries, etc. in addition to those that are employed in the electronics industry, high strength temperature resistant (HSTR) alloys of titanium, carbides, anamonics', and ceramics are also included in this category. Because of the wide variety of uses of tungsten alloy, these tungsten-carbide alloys present some unique machining opportunities. Tungsten carbide, because of its intricate forms and geometry, is notoriously difficult to produce using the conventional manufacturing technique. In hance high accuracy for machine tungsten carbide with good options include things like Automations, Non-traditional Machining (NTM), machining techniques are laser-beam-machining (LBM) & electron-beam-machining (EBM) and electric discharge machining (EDM), amongst others. The copper electrode was used in the machining of tungsten carbide, which had 93 percent WC and 7 percent Co, according to the authors of this paper. Machining is performed using an Automations-EDM MODEL-500 equipped with an X-300 ENC and a VELVEX EDMVEL-2. Additionally, the machine is equipped with Automation components such as real-time feedback sensors, handling systems, and a robot with dielectric oil. There 17 types of experiments have been done based on the RSM (Box-Behnken) method. Furthermore, Authors performed experiments, in order to locate the solutions that are the most effective overall combination grey relational analysis is used. The GRA technique illustrates that the ideal combinations for P-on-t (pulse-on-time) are 40 microseconds, P-off-t (pulse-off-time) for 2 microseconds, and current supply of 12 Ampere. Last, the confirmation experiment has been conducted.

Keywords: HSTR, Tungsten carbide, EDM, non-traditional, GRA and RSM.

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INTRODUCTION

With development in the manufacturing techniques; the demand of complex shapes (3D) and high accuracy is increasing daily. Sometime it is very difficult to meet the demand of high accuracy specification and complex shapes, due to limitation in the cast and number of manufacturing techniques. Among the difficulty of machining alloys (tungsten carbide) is a very hard material which is use because of its certain special properties like corrosive resistance, superior wear and high hardness. In today's world, there is a significant impact on the manufacturing of dies, specialized tools, and cutting tools produced of tungsten carbide and the composites or alloys of this material. because of certain properties like strength, high hardness wear resistance over rang of temperature. So, machining WC and its alloys are the main concern for the manufacturing over last few decades. therefore, to succeed in dealing with the difficulties of machining with conventional method of manufacturing unconventional method of manufacturing is being use for application where complex geometry and high accuracy are the primary requirement. Among the unconventional machining method EDM (Electrical discharge machining) process for cost effective and important method for the machining of brittle & extremely hard materials finding an appropriate tool material to machine these novel materials using traditional machining techniques is challenging. The Ceramics & tungsten with its alloys and high strength polymers and also the stainless steel and other alloys can be produced using hybrid materials by following the steps outlined in this article. there is a requirement for 2 innovative machining processes, often known as non-traditional machining techniques. These is possible to employ non-traditional machining methods to cut a variety of hard materials, regardless of their hardness. Author discus about the numerous non-traditional machining techniques, and the most of them are used for the same things, as a result, the energy utilized during non-traditional machining operations is frequently used to classify them [1]. The value of MRR, electrode wear, and the impact of flushing and material for electrodes, Surface roughness, copper electrode usage has been demonstrated to reduce surface roughness, and flushing improves both MRR and electrode wear [2]. The author describes that by using the work-piece is the anode and the electrode as the cathode, greater machining performance may be obtained, with a rise in open circuit voltage, the MRR drops, as peak current rises, the MRR rises as well until it reaches a constant value at high peak current [3].The author disused about the work was taken to have positive polarity, and finds the, MRR rises as peak current does, Peak current decreases as surface finishing increases, SiC powder concentration increases result in a decrease in MRR by using EDM machining of Al-SiC composite [4].The author discovered that the crucial variables for milling H-11 Die steel are peak current and silicon powder concentration [5]. In this study, the surface polish, relative volumetric wear, and MRR for tool steel AISI P20 are examined in relation to the effects of positive & negative polarity of copper with graphite electrodes [6]. Author found that, copper and graphite electrodes with a (-) ve polarity both produce the best results for surface roughness and MRR using Aluminium oxide powder can improve MRR and lower EWR [7]. The author discovered that large, deeper fissures emerge as a result of tremendous energy, more so than current, pulse-on-time effects dominate, after milling, the surface's chemical compositions changed [8]. The Author has been found the used of machine D2, die-steel electrode using copper, and acquired the most important combination of Peak current 10A, concentration of Powder -4 g/l & Pulse- on-time 100µs, and Pulse-off time15µs, gain 1mm/s, peak current, powder concentration stands out among the others [9]. The Author discus about the optimal parameter combination has been identified using RSM, GRA, and entropy analysis [10]. The Author discuss about the current are essential parameters to acquire higher values of MRR and lower values of TWR for machining Die steel H-13[11]. Author discus about comparison to other input parameters, and also made the discovery that the critical input parameter that is the most crucial for tungsten carbide alloy machining to be successful of the pulse on time [12]. According to, the author the pulse on time, has a significant impact on MRR, TWR is impacted by the current & pulse off time; Current is the most crucial element overall [13]. The author describes the thorough analysis demonstrates that 1.2g/l of La_2O_3 results in increased micro hardness and a 2.6% reduction in electrode wear rate [14]. We have been conducted 17 experiments used in Using a grey relational technique, the authors the results thorough analysis of the effects of multiple EDM process parameter, of the roughness of the surface, tool wear rate, and rate of removal of material, and microhardness were able to determine the relationships between these factors.

All the above literature review we found that the novelty that use GRA technique illustrate with SRM methodology of (WC = 93%, Co = 7%) workpiece, with EDM machining method to find optimum solutions. Some of among the unconventional/non-traditional machining processes shown in Table 1.

Table1: Classification of unconventional manufacturing techniques

Unconventional manufacturing processes				
Mechanical	AJM	WJM	USM	AWJM
Chemical	CHM	PCM		
Electro-chemical	ECM	ECM	ECM	
Thermo-chemical	EDM	EBM	LBM	IBM

1. Electrical discharge machining

The Joseph Priestley made the discovery of electrical discharge machining since 17th century in 1766. This machining method is not conventional [15]. The working principle of EDM machining process is sparking generations and the

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spark erosion is used to remove metal. EDM spark erosion is identical to electric spark erosion in that both create a small hole in the metal through which metal comes into contact. In the EDM process high frequency is use to generate spark between tool and workpiece to produce heat which remove metal by evaporation and erosion will show in Figure 1 In this process most important things that both material workpiece and tool must be made of conductive material.

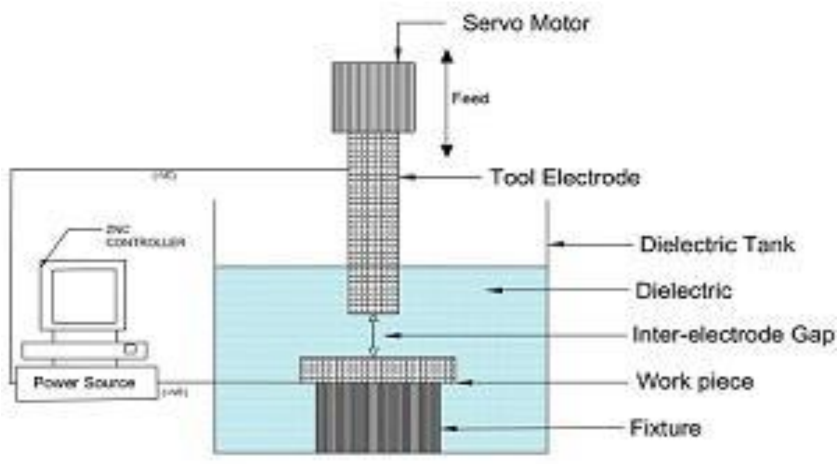

Fig.1: Electrical discharge machining (EDM) process

This method's rising popularity can be attributed to the fact that it is able to machine extremely tough and electrically conductive materials, the likes of which are notoriously difficult to machine using traditional methods [16]

1. Machining of outer surface is alteration properties
2. After machining its required post processing
3. The formation of micro cracks and heat effected zone
4. Material removal rate is very slow processes
5. In order for scientists to overcome these challenges, they have turned to abrasives including silica, aluminium oxide graphite, silicon carbide, and others in order to obtain greater performance.

3. Experiment details

The EDM MODAL 500 X 300 CNC, Machining is use for experiment, which can be seen in Fig. 1 for design view, is now serving as the experimental platform for the current study. The workpiece is made of an alloy of tungsten carbide with a composition of 7% cobalt, and the electrode material is made of electrolytic copper. The details and specifications are provided in Table-2, which will be given below, but the experiment will be conducted with EDM oil VELVEX LEVEL-2. After machining MRR is calculate the change in weight of material are calculated from initial weight to final weight of workpiece. Each experiment is conducted in same conditions as show in equations (5).

$$MRR = \frac{W_i - W_f}{t \times d} \quad .... (5)$$

Where initial weight is w_i (in gm) and the final weight is w_f (in gm), t is the amount of time spent milling, and d is the density (in grammes per cubic millimetre). For calculating MRR in weighting machining which having a least count 0.0001gm.

3.1 Electronic weighting machine

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In Fig2: will show an electronic weighing machining, which capable to measure weight up to 4 decimal places. The weight of samples can be measure before and after machining for proposes of MRR and TWR Each samples measure weight thrice or three time and average values were taken. Figure 2 depicts a machining sample of a workpiece. There are 17 sample workpieces collected for 17 times of experimentation.

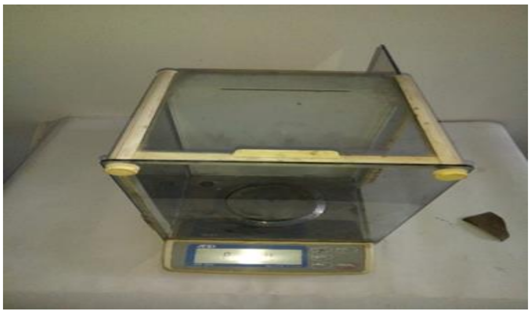

Fig.2: Electronic weighing machine**.**

Table 2: Both the tool & the work-piece have certain properties and specification

S.No.	Properties	Details	Properties	Details
1.	Tools		Work-piece	
2.	Materials	Electrolytic (Copper-Cu)	Material	Tungsten carbide (WC)
3.	Compositions	99.9 percentage of copper	Compositions	WC = 93%, Co = 7%
4.	Point of Melting	1083^0C	Point of Melting	2870^oC
5.	Electrical ohmic resistance	9μΩcm	The thermal conductivity, denoted by "k,"	100W/mK
6.	Density	$8.924g/cm^3$,	Hardness	85 HRC
7.	Dimensions	17mm in diameter. 20mm in height	Dimensions	25mm in diameter 9mm in height
8.	------	-------	Density	$14.8\ g/cm^3$

The characteristics of the work-piece & tool is displayed in Table.2 In the Fig.3 (a) and (b) will show the sample of workpiece after EDM machining these are total 17 experiment are done on each sample of workpiece. The 3D-designing view of an electrode is shown in Fig. 4. And the real electrode is depicted in Fig. 5. Table 3 displays the input parameters that remain constant throughout the experiment, as well as the variable input parameters and factor level that alter throughout the experiment are displayed in Table 4.

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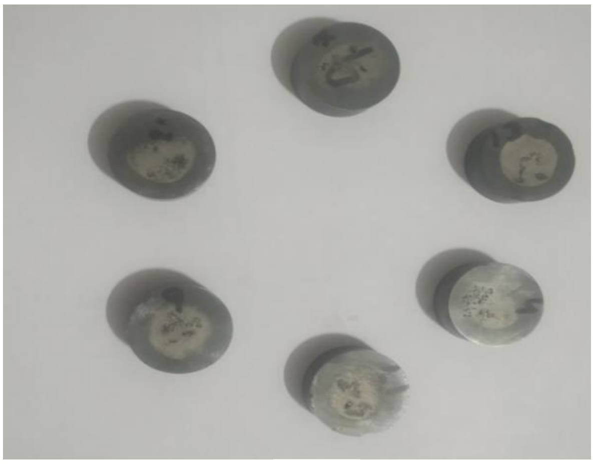
(a)



(b)

Fig.3: Work-Pieces

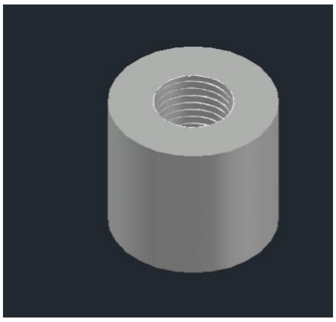


Fig.4: 3D view of Electrode

Fig.5: Electrolytic Copper Electrode

Table 3: Specification of fixed input parameters

S.No.	Input Parameter (fixed)	Specifications
1.	Workpiece	Alloys of Tungsten carbide
2.	Tools	Copper,
3.	Dielectric fluids	VELVEX EDM VOL-2
4.	Supplied voltage (v)	200 volts

Table 4: Specification of variable Input-parameters and its level

S.No.	Factor	Level (-1)	Level (0)	Level (1)
1.	Pulse-on-time (T_{ON}) in micro-second	10	25	40
2.	Pulse-off-time (T_{OFF}) in micro-second	2	5	8
3.	Current in Ampere	6	12	18

3.2 Micro-hardness:

The micro-hardness is material properties which calculated by applied load (P) as well as the mean of the imprint's diagonals (d). An indenter that has the shape of a square pyramid & it has an apex angle of 136° is utilised. The equations used to derive the hardness number are as follows: (6)

$$HV = 1.854 \frac{P}{d^2} \text{................}6$$

Where P, is denote is applied load and it's measured in newtons, and d is the mean value of the both diagonals which is measured in millimetres, respectively. The Micro hardness was determined with the assistance of a micro hardness tester made by omnitech Industries in Pune, India (Model MVH-S AUTO). The quantimeter software is used to measure the diagonal size of the imprint. On each sample, there was a single application of a load of 1 kilogramme for a dwell time of 15 seconds.

3.3 Surface roughness:

A Perthometer (Model SJ-30 made by Mitutoyo in Japan) is used to test the smoothness of the surface. After machining, the smoothness of the surface is measured using roughness tester as show in Fig.6. All the surface roughness were measured thrice a times and average value were taken as seen in equation (7), the arithmetic mean value, often known as Ra, is what's used to determine whether a surface is smooth or rough.

$$Ra = \frac{1}{L}\int_0^L h(x)dx \text{..............}7$$

Between 0.01 and 100 micrometres is the range that surface roughness can be measured in. Each sample of the workpiece had its surface measured three times in different locations with three places, and the average of those measurements was used to determine the surface roughness value. Each and every time, a tracing length of 2.5 millimetres is used.

Fig.6: Roughness tester

3.4 Objectives

The studies offer an exhaustive examination of the determinants influencing MRR and TWR in EDM for high strength temperature resistant (HSTR) alloys of titanium, carbides, anamonics', and ceramics are also included in this category. It is important to contemplate the possible problems with the Grey method and ANOVA. These methods presume linear relationships and may inadequately represent intricate interactions among parameters. Using ANOVA to improve machining efficiency by optimizing material removal rate (MRR) and tool wear rate (TWR) on die tungustan carbid is an important part of the process. The Author applied grey relations approach to optimize the EDM parameters for the experimental procedure, consequently decreasing the number of experiments while preserving rigorous statistical analysis. ANOVA was used to figure out how important different machining parameters were to MRR and TWR. The method helped us understand which factors had the most significant effect on these results. It has been observed that from the initial setting of $A_1B_1C_2$The micro-hardness increases from 1239 to 1361, the roughness of surface decreases (Ra) from 1.86 to 1.26, and the MRR increases from 1.0477 to 2.3046. Additionally, The GRG value has increased all the way up to 0.8632 from its previous level of 0.4529.

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4. Methodology

4.1 Optimizing EDM parameters

In this, Author applied grey relations approach to optimize the EDM parameters.

4.2 Basic concept of GRA

In this this the grey relation analysis is based on theory of (Deng, J. L, 1989). which is called grey theory, its theory is very effective on multi-input parameter of data. The author of this study discovered applications of GRA in a variety of fields, including industrial engineering and weather forecasting.

The Steps which use in GRA is as fallowing given bellow.

1. Normalised the results of Experimental values.
2. Calculate the upper and lower deviations sequence.
3. Determine the GRC, or grey relations coefficient, which will indicate the relationship between the normalised experimental findings and the ideal results; this will be done by calculating it.
4. In order to compute the GRG, or grey relation grade, which are arithmetic's mean of the GRC, or grey relation coefficients.
5. a ranked list of grey relation grades has been provided, which will produce the best possible outcome.

The normalised values obtained as mention instep 1 which are using in equation (1) "higher is better" for MRR material removal rate & "lower is better" for surface smoothness.

$$x_i^*(k) = \frac{x_i^o(k) - min.x_i^o(k)}{max.x_i^o(k) - min.x_i^o(k)} \quad (1)$$

$$x_i^*(k) = \frac{max.x_i^o(k) - x_i^o(k)}{max.x_i^o(k) - min.x_i^o(k)} \quad (2)$$

Where as $x_i^*(k)$represents the normalised value of the original sequence$x_i^o(k)$ represents, ith sequence of the original sample, $x_i^o(k)$represents the maximum value that the initial sequence may have & $x_i^o(k)$ is the original sequence's lowest value that can be obtained.

4.3 GRC (grey relational coefficients)

Its Grey relations coefficient $\gamma_{0,i}(k)$ is represent the relationship between normalise value result and Ideal value result. The GRC coefficient is describe in equation (3).

$$\gamma_{0,i}(k) = \frac{\Delta_{min} + \varepsilon\Delta_{max}}{\Delta_{0i}(k) + \varepsilon\Delta_{max}} \quad (3)$$

The minimal deviational sequence is denoted by the symbol Δ_{min} the maximum deviational sequence is denoted by the symbol Δ_{max}, the deviational sequence is denoted by the symbol $\Delta_{0i}(k)$and a differentiating coefficient that has a range from 0 to 1 is set at 0.5 from (Deng, J. L, 1989).

4.4 GRG (Grey relational grade)

As seen in equation (4), it represents the expression of the arithmetic mean of the grey relations coefficient, which is called the grey relations coefficient.

$$\beta_i = \frac{1}{n}\sum_{k=1}^{n} \gamma_{0,i}(k) \quad (4)$$

where β_i is the GRG for the ith experiment and n represents the total number of observations.

4.5 GRA (grey relational analysis)

In the grey relational analysis (GRA), the RSM technique (Box-Behnken of 5 centre points) utilised 17 independent tests to normalise the values of MRR & MH, and surface roughness (Ra) into the range of 0 to 1 by applying equations

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(1) and (2). In the grey relational analysis & the RSM technique (Box-Behnken of 5 centre points) utilised 17 independent tests to normalise the value of removal rate of material (MRR) with micro hardness (MH) and roughness of surface (Ra) into the range of 0 to 1 by applying equations (1) and (2). This was done so that the results could be compared more easily. Table 8 presents the findings obtained from conducting this research. Equation 3 is used to calculate the GRG values, which in turn are used to determine the relationship between ideal and normalised values. These values can be found by following the formula. And GRG value is calculated from GRC from using eq. (4). The rank wise list is allotted from all the GRG value in the Table: 8 displays the data in descending order from highest to lowest maximum. And also, the calculations for average value from grey response from all the input parameter as its show in the Table: 8 In this paper the pilot test is carried out evaluations of machining of tungsten carbide (WC) using copper and graphite electrode and by using RSM (Box-Behnken) with 5 centre points. The Experiments are planned according to method technique with factors at three different levels using design expert (version11.1.2.0) there are 17 experiments obtained using 5 centre points. we found that copper electrode is more suitable for machining tungsten carbide (WC=93%, and Co= 7%) alloy.

4.6 The experimental is perform modelling by RSM (response surface technique)

In this paper there are total 17 experiment performed on tungsten carbide by using copper electrode, will be show in the Table 5. the RSM methodology is use to evaluate the model as described below.

1) Material Removal rate (MRR) by RSM methodology

2) Surface roughness (SR) by SRM methodology

4.7 RSM for Material removal rate (MRR)

It shows the quadratic model for the evaluation of material removal rate. The F-value for the modal is 31.25. The significant model is shown in Table 6. The value of R-square 97.57 % & The value for R-square is 94.45%. (Singh et al. 2015) said that if the value of R-square is nearly one-unit, 100 percent of it means that it has good conformity and explanation of experiment. The P-value of its model is less than 5 percent. Its statistically significant modal. The study shows that Pulse-on-time (T_{ON}) is 74.202 percentage which is the most significant contribution with current 11.43% contributions. It is desirable since the lack of fit, is not significant and hence desirable. Table 6. reveals that the value of the Coeff. variable is 7.58%, indicating that the model has a high degree of accuracy. After removing non-significant value, the coded Equations for the MRR is given bellow.

(Coded Equation)

$$MRR=1.36338+0.5909375*A-0.0649625*B+0.23185*C-0.1835*AB+0.144375*AC-0.021525*BC+0.237985*A^2+0.074785 * B^2 + 0.03256 * C^2$$

(Actual Equation)

$$MRR=0.921878-0.0123508*A + 0.012358* B -0.01719* C - 0.00407778*AB+0.000160417*$$

$$AC - 0.00119583*BC + 0.00105771* A^2 + 0.00830944* B^2 + 0.000904444* C^2$$

4.8 RSM for Surface roughness (SR)

It showed the quadratic model for the evaluation of surface roughness. The F-value for modal is 24.45. the significant modal is shown in Table 7. The value of the R-square is 96.92 % & value of Adj. of R-square 92.95%. (Singh et al. 2015) said that the values of R-square are approximately unit or can say that 100 % means the good conformity and explanation of experiment. The P-value of the modal is less than 0.05 and it shows an important/significant statistics model. It's found that the Pulse-on-time (T_{ON}) is most Important/significant with 32.382% of contribution followed by current having 24.018% of contributions. The lack of fit is not significant which means it is desirable. Table.7 will show that the value of Coeff. of variance is 8.99 % which shows good accuracy.

After removing the non-significant values, the coded Equations for surface roughness is given bellow.

(Coded Equations)

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SR=2.038-0.30625*A+0.7675*B-0.26375*C-0.0975*AB+0.28*AC+0.0725*BC+0.7485*A^2-0.419*B^2 +0.4185*C^2

(Actual Equation)

SR=5.29019-0.21325*A+0.727222*B-0.420875*C-0.00216667*AB+0.00311111*

AC+0.00402778*BC+0.00332667*A^2+0.046556*B^2+0.011625*C^2

4.9 Box-Behnken with output value of response characteristics

The experimental are design are using RSM (Box-Behnken) with 5 centre point. In Table.5. the Experiment are planed according to method technique with for factor at three different level using design expert (version 11.1.2.0). there are 17 combinations obtained using 5 centre point.

Table 5: Experimental design of Box-Behnken with output values of response characteristics

		Factor 1	Factor 2	Factor 3	Response 1	Response 2
Std	Run	A: T_{ON}	B: T_{OFF}	C: Current	MRR	SR
11	1	25	2	18	1.7972	1.06
3	2	10	8	12	1.3067	3.74
7	3	10	5	18	1.0443	2.79
1	4	10	2	12	1.0447	1.86
6	5	40	5	6	1.9348	3.06
4	6	40	8	12	1.9406	2.68
10	7	25	8	6	1.1873	2.87
16	8	25	5	12	1.2737	2.19
12	9	25	8	18	1.5993	2.59
5	10	10	5	6	0.8607	3.98
8	11	40	5	18	2.6959	2.99
9	12	25	2	6	1.2991	1.63
15	13	25	5	12	1.4512	2.26
2	14	40	2	12	2.4126	1.19
14	15	25	5	12	1.2991	1.83
17	16	25	5	12	1.3486	1.97
13	17	25	5	12	1.443	1.93

5. Results

After Using ANOVA to improve machining efficiency by optimizing material removal rate (MRR) and tool wear rate (TWR) on die tungustan carbid is an important part of the process. In the grey relational analysis (GRA), the RSM technique (Box-Behnken of 5 centre points) utilised 17 independent tests to normalise the values of MRR & MH, and surface roughness (Ra).Following results is obtained.

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Source	SOS	DOF	Average Square (Mean Square)	F-value	P-value	
Model	3.76	9	0.4176	31.25	< 0.0001	significant
A - T_{ON}	2.79	1	2.79	209.04	< 0.0001	
B - T_{OFF}	0.0338	1	0.0338	2.53	0.0156	
C- Current	0.4300	1	0.4300	32.18	0.0008	
AB	0.1347	1	0.1347	10.08	0.0156	
AC	0.0834	1	0.0834	6.24	0.0411	
BC	0.0019	1	0.0019	0.1387	0.7206	
A^2	0.2385	1	0.2385	17.84	0.0039	
A^2	0.0235	1	0.0235	1.76	0.2260	
C^2	0.0045	1	0.0045	0.3340	0.5814	
Residual	0.0935	7	0.0134			
Lack of Fit	0.0669	3	0.0223	3.35	0.1369	not significant
Pure Error	0.0267	4	0.0067	R^2	0.9757	
Cor Total	3.85	16		Adjusted R^2	0.9445	
C.V. %	7.58			Predicted R^2	18.5534	

Table:6: The MRR ANOVA

Table 7: ANOVA for the Roughness of the Surface

Source	SOS	DOF	Average Square (Mean Square)	F-value	P-value	
Model	23.17	9	1.13	24.45	0.0002	Significant
A- T_{ON}	7.503	1	0.7503	16.24	0.0050	
B- T_{OFF}	4.71	1	4.71	102.00	< 0.0001	
C-Current	5.565	1	0.5565	12.05	0.0104	
AB	0.0380	1	0.0380	0.8230	0.03945	
AC	0.3136	1	0.3136	6.79	0.0352	
BC	0.0210	1	0.0210	0.4551	0.5216	

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A^2	2.36	1	2.36	51.06	0.0002	
B^2	0.7392	1	0.7392	16.00	0.0052	
C^2	0.7374	1	0.7374	15.96	0.0052	
Residual	0.3234	7	0.0462			
Lack of Fit	0.1935	3	0.0645	1.99	0.2583	Not Significant
Pure Error	0.1299	4	0.0325	R^2	0.9692	
Cor Total	10.49	16		Adjusted R^2	0.9295	
C.V. %	8.99			Predicted R^2	0.6855	

Table 8: Measurements of MRR, Micro-hardness, and Surface Roughness, as well as GRA values

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Normalized Value			Grey Relational Coefficients			Grey Relational Grade	
MRR	MH	SR	MRR	MH	SR		RANK
0.5101	0.4066	1.000	0.5045	0.4572	1.000	0.6538	3
0.2428	0.000	0.0820	0.3974	0.3331	0.3525	0.3610	16
0.1000	0.0845	0.4072	0.3570	0.3530	0.4575	0.3891	15
0.1001	0.0930	0.7258	0.3571	0.3552	0.6455	0.4525	12
0.5851	0.7371	0.3150	0.5464	0.6554	0.4218	0.5412	5
0.5000	0.7072	0.4450	0.5482	0.6275	0.4735	0.5500	4
0.1778	0.1440	0.3800	0.3780	0.3686	0.4463	0.3976	14
0.2248	0.3812	0.6128	0.3921	0.4469	0.5635	0.4674	11
0.4023	0.2371	0.4758	0.4554	0.3958	0.4881	0.4465	13
0.0000	0.0591	0.0000	0.3331	0.3468	0.3331	0.3377	17
0.1000	0.9574	0.3390	1.0000	0.9216	0.4305	0.7840	2
0.2387	0.1778	0.8046	0.3961	0.3778	0.7190	0.4978	6
0.2316	0.3388	0.5891	0.4241	0.4305	0.5487	0.4676	10
0.8454	1.000	0.9553	0.7638	1.0000	0.9180	0.8938	1*
0.2387	0.1184	0.7361	0.3964	0.3610	0.6545	0.4705	9
0.2657	0.2286	0.6881	0.4046	0.3931	0.6158	0.4711	8
0.3178	0.1692	0.6984	0.4231	0.3755	0.6235	0.4740	7

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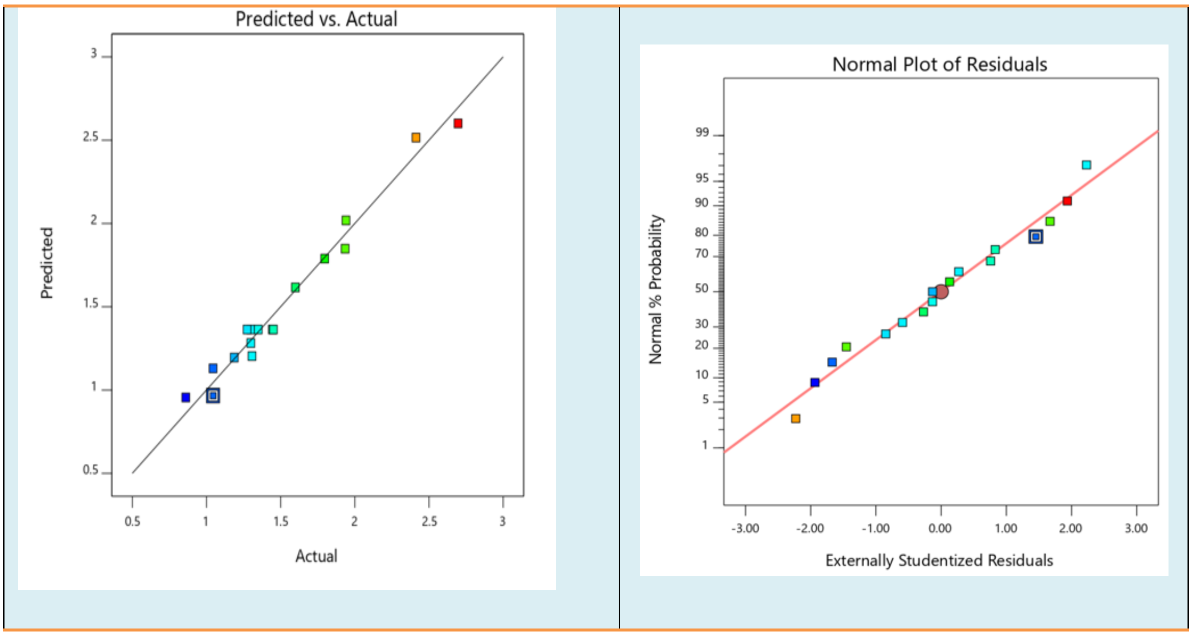

Fig.7. (a) Graph between actual vs predicated response for surface roughness (SR), (b) Normal Probabilities plot residuals.

Additionally, Table. 8: Provides information on the grey relational grade. The highest and lowest values of the grey relation grade establish the rank. Fig.7 (a) As show the plot of graph between actual vs predicated response for SR after viewing the graph is can said that regression modal is effectively implemented. Fig.7 (b) shows the graph normal probabilities plot residual. It is observed that residual is closed to straight line. it can be said that error is distributed normally. Fig.8 (a) Show the plot a graph actual vs predicted response for MRR. After viewing the graph, it is said that the regression model is effectively implemented. Fig.8 (b) shows the graph normal probability model is effectively implemented. In science we notice that the residuals are close to straight line implying that errors are normally it can be said that errors are distributed normally.

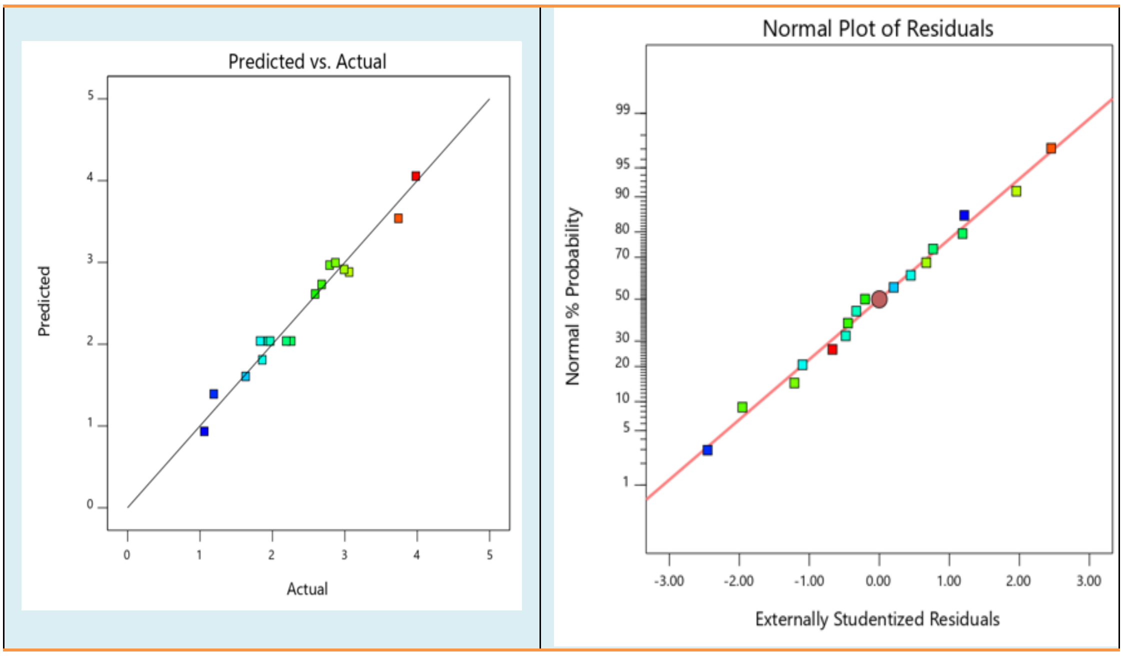

Fig. 8. (a) Graph between actual vs predicted response for MRR, (b) Graph normal probability plot residual.

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Fig.9: shows a 3D predicted response graph for removal rate material (MRR) with decency to T_{ON} and current parameter. It can be observed the MRR increase with increases in P-on-time and current. The highest possible MRR value is attained. at a maximum value of T_{ON} that is 40µs and current at maximum 18 Amps. It can also be said that as we increase the T_{ON} the MRR increases it happens because as we raise T_{ON} the amount of time for which spark occurs increases which lead to high melting of work-piece higher values of MRR. The same can be said about the current as we increase the current spark intensity increase which leads to strengthening in pulsation with higher melting of tungsten carbide

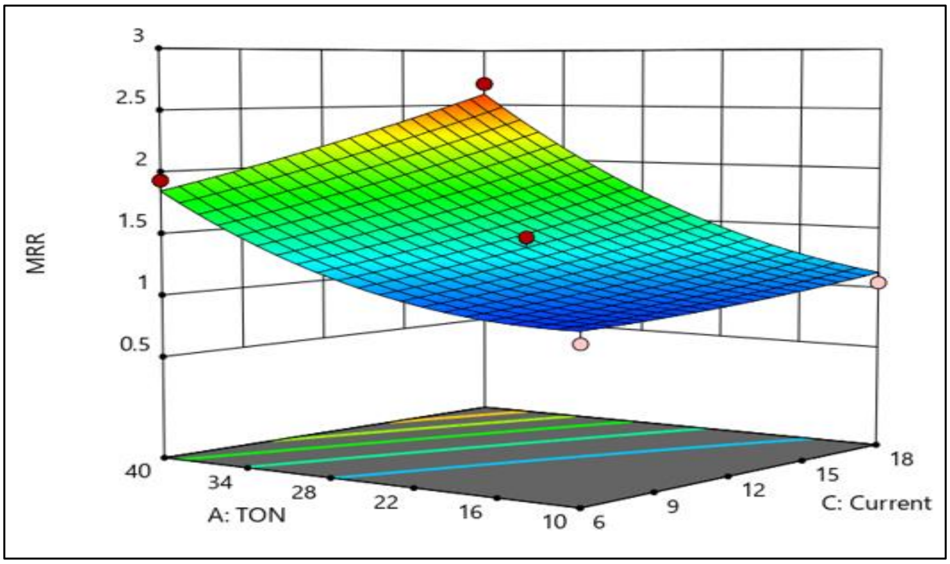

Fig. 9. Calculated response of MRR vs pulse on time and current

Fig.10: shows a 3D predicted response graph for surface roughness with respect to T_{ON} and current parameter. It can be observed that surface roughness generally decreases rather than increases with rise in P-on-time (T_{ON}) and current. Maximum value of SR obtained at maximum value of T_{ON} is 40µs and the maximum value of current is 18 Amps. It can also be said that as we increase the T_{ON} the amount of time the spark increases which leads to high melting and lower amount of time for flushing to take place which lead to the formation of defect like mirror cracks alumina powder layer, coagulation which generally causes change in surface roughness.

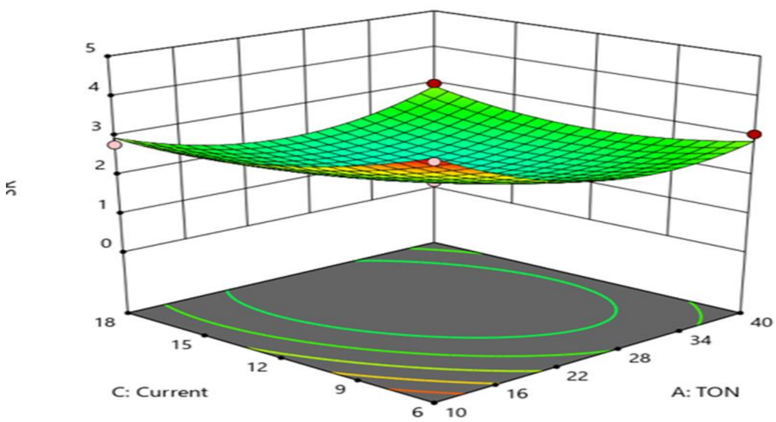

Fig. 10: Calculated response of SR vs pulse on time and current

6. Optimization of Output Response

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As show in the above section that it's difficult to find optimal combination as parameter come out to be in the favour of machining characteristics and some in the favour of surface characteristics. In light of this, it's necessary to carry out multi-objective optimisation in order to locate the parameters or combination that is optimal. The Table.8 contains the normalised data, as well as the grey relation coefficient and the grey relational grade values. Also, Table. 8 gives us details about grey relations grade and the rank is given out based on the order of the highest possible value to the lowest possible value of the grey relations grade. The Table.5 show that experiment no 14 is the best combinations among the 17 combinations. The current is 12 amps, and the pulse-on duration is 40 microseconds, while the pulse-off time is 2 microseconds. The star (*) symbol indicates the best combinations, in Table.9 and also show the average grade value of all the levels. According to the Table.9, By setting the pulse-on-time (T_{ON}), the best possible result is obtained at level-(+1), and the pulse-of-time (T_{OFF}) level-(-1), current at level-(0), gives the optimal solutions. The Max-Min column reveals that, of the three input parameters, the pulse-on-time (T_{ON}) is the one of that bears the highest significance from the Table.9 below shows the calculations for the average value from the grey response for each input parameter:

Table 9: Values of GRG that are averaged over all of the levels

Grey relational grade Parameters	Level {-1}	Level {0}	Level {+1}	{Max-Min}	Rank	Symbol
T_{ON} (μs)	0.3853	0.4832	0.6924*	0.3071	1	A
T_{OFF} (μs)	0.6248*	0.4896	0.4389	0.1859	3	B
Current (A)	0.4437	0.6312*	0.5686	0.1875	2	C
The overall mean of the grade for grey responses is 0.5286						

From the confirmatory experiment it's found that the out predicted GRG value from of equation (8)

$$\alpha = \alpha_m + \sum_{k=1}^{n} (\alpha_k - \alpha_m) \quad (8)$$

Where is the α_m = average of all the GRG values
α_k equals the average of the GRG value at the lowest possible rank in order to optimise the machining parameters for tungsten carbide alloy.

Table 10: Confirmatory experiments

		Optimal parameter	
Process parameters	Initial values ($A_1B_1C_2$)	Predicted	Experimental ($A_3B_3C_1$)
MRR	1.0447	-	2.3046
MH	1239	-	1361
SR	1.86	-	1.26
GRG	0.4529	0.8822	0.8632

7. Conclusion

In Table 10, the initial values are taken as $A_1B_1C_2$ and $A_3B_1C_2$ are the optimal setting. It has been observed that from the initial setting of $A_1B_1C_2$The micro-hardness increases from 1239 to 1361, the roughness of surface decreases (Ra) from 1.86 to 1.26, and the MRR increases from 1.0477 to 2.3046. Additionally, The GRG value has increased all the way up to 0.8632 from its previous level of 0.4529. In light of the aforementioned findings, one can deduce that the grey relation a model has been successfully integrated. The primary purpose of the article is to determine which of the 17 tests yields the most favourable combination. In order to deal with the numerous objective data, the GRA approach is utilised. Within the parameters that were provided, the optimal combination for the machining of tungsten carbide was effectively obtained. The results of the experiments indicate that experiment 14 is the most effective combination, with a pulse-on-time (T_{ON}) of 40 microseconds, a pulse-off-time (T_{OFF})of 2 microseconds, and a current of 12Amperes on this input parameter the experiment achieved the highest GRG value

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