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Optimization of EDM Characteristics of WC/5ni Composites Using Response Surface Methodology

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Abstract: Electric discharge machining (EDM) has achieved remarkable success in the manufacture of conductive ceramic materials for the modern metal industry. The mathematical models are proposed for the modeling and analysis of the effects of machining parameters on the performance characteristics in the EDM process of WC/5Ni, Which is produced through powder metallurgy route. Response surface methodology (RSM)is used to explain the influences of four machining parameters ; tool rotational speed(S), discharge current(C), pulse-on time(T) and flushing pressure(P) on the performance characteristics of the material removal rate (MRR), and surface roughness (Ra). The experiment plan adopts the central composite design (CCD). The separable influence of individual machining parameters and the interaction between these parameters are also investigated by using analysis of variance (ANOVA). This study highlights that the proposed mathematical models have proven to fit and predict values of performance characteristics close to those readings recorded experimentally with a 95% confidence interval. Results shows that are the two significant factors affecting material removal rate (MRR) are discharge current and flushing pressure. The discharge current, flushing pressure and electrode rotation have statistical significance on the surface roughness (Ra).

Key Words; Electro discharge machining (EDM), Material removal rate (MRR), Surface roughness (Ra), Response surface methodology (RSM)

I. INTRODUCTION

Electric discharge machining (EDM) is a technique used in industry for high-precision machining of all types of conductive materials such as metals, metallic alloys, graphite, ceramics, etc. Material of any hardness can be machined as long as material can conduct electricity. Since researchers have encountered major difficulties due to complexities of physics in EDM process, the physical models are found to be far away from reality [1].T. A. El-Taweel et al describes that the Electrical discharge machining (EDM) has become one of the most extensively used non-traditional material removal process. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage in the manufacture of mold, chuck, die, automotive, aerospace, and surgical components [2].

The higher the MRR, the better, whereas the lower the tool wear, the better. In a single objective optimization, there exists only one solution. But, in the case of multiple objectives, there may not exist one solution, which is the best with respect to all objectives.

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In EDM process, it is difficult to find a single optimal combination of process parameters for the performances parameters, as the process parameters influence them differently. Hence, there is a need for a multi-objective optimization method to arrive at the solutions to this problem. Classical methods for solving multi-objective problem suffer from drawback. These methods transform the multi-objective problem into single objective by assigning some weights based on their relative importance [3]. Also, these classical methods fail when the function becomes discontinuous. C.J. Luis and I. Puertas [4] introduced a new methodology for developing technological tables used in EDM process for machining of conductive ceramics material. Techniques of design of experiments and multiple linear regressions are used. A second order mathematical model was developed and evaluated to predict the optimal conditions suitable for electric discharge machining of Aluminum Matrix Composites (AMC) over the listed technological characteristics.

D Kanagarajan et al. [5] developed models for the MRR and Ra over the most influencing process parameters in EDM of WC/30% Co composites. The RSM methodology is used to identify the most influential parameters for maximizing metal removal rate and for minimizing the surface roughness. Luis et al. [4] have applied the second-order models to carry out studies of MRR and TWR. In the case of MRR, the only influential design factors, for a confidence level of 95 per cent, are intensity and voltage. With regard to EW arranged in descending order of importance, intensity, pulse time, and flushing pressure turned out to be the influential factors for a confidence level of 95 per cent. The variation tendency of TWR obtained in the case of intensity is the one that was anticipated, whereas the opposite behavior applied in the case of pulse time. Kanagarajan et al[6]. applied a multi objective optimization tool such as the non-dominated sorting genetic algorithm (NSGA-II) to optimize the EDM characteristics of WC/Co composites. In this study they did not identify the interaction effect of the input parameters M.K.Pradhan etal[7] investigated the machining performance such as Surface Roughness, electrode wear rate and MRR with copper electrode and AISI D2 tool steel workpiece and the input parameters taken are current(Ip), pulse on time(Ton), and pulse off time(Toff). The optimum condition for Ra was obtained at low Ip, low Ton, and Toff and concluded that the Ip was the major factor effecting both the responses, MRR and Ra. WC-based cemented carbides provide the majority of turning tools, milling cutters and mining tools, In the fields of aerospace and automobile they are more and more applied for their ultra-hard, erosion/friction-resistant and high temperature resistant properties.

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The toughness and strength of these materials can be tuned by adding an adequate amount of metallic binder to the WC powder during the liquid phase sintering process. Generally, cobalt (Co) is selected as binder material owing to the excellent wettability between Co and WC [5] and the outstanding characteristics of WC–Co alloys. The cobolt material is replaced by nickel for increasing the corrosion properties and to the favourable self- fluxing properties [3].

Consequently, an analysis on the influence of current intensity, pulse time, flushing pressure and electrode rotation over technological variables such as: material removal rate and surface roughness was performed. This was done using the technique of design of experiments (DOE) and multiple linear regression analysis. The combined use of these techniques has allowed us to create both first and second-order models, which make it possible to explain the variability associated with each of the technological variables studied in this work. The response surface methodology (RSM) is used to get proper parameter setting for desired responses. Development of mathematical model with interaction and higher degree effect of factors for further analysis and checking the fitness of the developed model through ANOVA have also been done.

II. EXPERIMENTAL STUDY

The metal powders are constituted of hard tungsten carbide and nickel, which is dry in nature, so the Poly Vinyl Alcohol (PVA) binder is added to obtain a more stable body after pressing. All ingredients are mixed in double cone mixer with alcohol to facilitate the homogenization of the powders. Proper mixing of the powder is essential for uniformity of the finished product. Mixing is carried out mainly to produce uniform distribution of particles

The high carbon high chromium steel material is used for fabrication of dies, it should be highly polished and the clearance between them should be kept at the minimum for proper alignment. Clearance should be sufficient to allow a free movement. The tooling used for compaction of cylindrical specimen is shown in Fig.1 Hydraulic press are best suited for parts of uniform density. In this research the 150-ton capacity hydraulic press is used for producing green compacts of tungsten carbide and nickel composites. The hydraulic press in pressing action of different dies is shown in Fig.2. The usual sequence of operations in die compacting include filling of die cavity with a definite volume of WC/Nickel powder, application of the required pressure by movement of the upper and lower punches towards each other, and finally ejection of the green compacts by the lower punch. The pressure applied ranged from 650-750MPa depending on the composition.

After compaction process are over the material is subjected to sintering, it is the process where by compressed metal powder is heated in a controlled atmosphere furnace to temperature below its melting point, but sufficiently high to allow bonding (fusion) of the individual particles.

Fig. 1 Cylindrical die

F ig. 2 150-Ton Hydraulic press

Fig. 3 Sintering Furnace

Fig. 4 Electro discharge machining setup

The sintering is carried out at tubular sintering furnace as shown in Fig.3. The governing variables in sintering are temperature, time and the atmosphere in the sintering furnace. Sintering temperature is generally within 70 to 90 percent of the melting point of the metal or alloy. The specimens are sintered at a temperature of 1250^{o}C for 12hrs to get the required density. Table I shows the compositions used and density achieved.

Table I. Composition of composites

Types of composition	Green density, g/cc	Sintered density, g/cc
95WC-5Ni	11.3	12.5

As the green compact is heated, the sintering process starts with bonding of particles. Bonding involves diffusion of atoms where there is intimate contact between particles leading to the development of grain boundaries. These inter particles bonding causes a large increase in strength and hardness even after short exposures to an elevated temperature. During sintering the formation of surface oxide films is avoided, since bonding between particles is greatly affected by surface oxide films. This is achieved by providing a controlled protective atmosphere during sintering. In this study argon atmosphere is used as sintering medium.

A. Electro Discharge Machining

The equipment used to perform the experiments is a die sinking EDM (Electronica-M100 MODEL) machine, is shown in Fig.4. It is equipped with transistor switched power supply. The electrode is fed downwards under servo control into the work piece. Copper cylindrical electrode of 12mm diameter is used as tool.

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Kerosene is used as a dielectric fluid. The dielectric fluid is circulated by jet flushing. One of the primary objectives is to study the effect of rotation of tool. Therefore, a mechanism to rotate the tool is developed.

The electrode is rotated and sunk simultaneously to machine a hole in the work piece. An electric motor is used to rotate the electrode (tool). A V belt is used to transmit the power from the motor to the electrode. The speed of the rotating electrode is controlled with the help of the regulated power supply. A mechanical tachometer is used to measure the speed of the rotating electrode. Hence all the experiments are performed with current, pulse on time, flushing pressure and electrode rotational speed as variables. The ranges of these parameters are selected on the basis of preliminary experiments conducted by using one variable at a time approach. Table II gives the levels of various parameters and their designation.

Experiments have been conducted according to central composite design covering full range of current and pulse on time settings to collect more number of data for modeling. For each experiment, a new set of tool and work piece has been used. The experiments are conducted on 95WC-5Ni composites .The response variables selected for these studies are Material Removal Rate (MRR) and Surface Roughness (Ra). The MRR has been calculated using the following expression

$$MRR(mg/min) = \frac{\text{Volume of metal removed from part}}{\text{Time of machining}}$$

The surface roughness has been measured on a Surfcoder SE1200 surface testing analyser. For each sample, 5 readings of surface roughness have been taken and average value of those 5 readings has been considered as the final reading. The results are presented in Table III

Table II. Process parameters and their levels

#	Factors	coded -2	-1	0	+1	+2
1	Rotational speed (S), rpm	200	300	400	500	600
2	Current (C), A	10	15	20	25	30
3	Pulse on time (T), µs	400	500	600	700	800
4	Flushing pressure (P), Kg/cm^2	1.0	1.25	1.5	1.75	2.0

Std order	Runorder	S	C	T	P	MRR (mg/min)	Ra(m)
1	2	300	15	500	1.25	3.36	14.2
2	8	500	15	500	1.25	6.03	14.2
3	21	300	25	500	1.25	9.36	22.683
4	6	500	25	500	1.25	9.03	22.04
5	10	300	15	700	1.25	4.36	20.551
6	13	500	15	700	1.25	3.03	16.908
7	20	300	25	700	1.25	8.36	25.034
8	9	500	25	700	1.25	11.03	21.391
9	26	300	15	500	1.75	15.91	19.612
10	5	500	15	500	1.75	14.58	17.969
11	3	300	25	500	1.75	13.91	14.095
12	22	500	25	500	1.75	12.58	23.452
13	23	300	15	700	1.75	14.91	18.963
14	12	500	15	700	1.75	13.58	15.32
15	29	300	25	700	1.75	15.91	18.446
16	11	500	25	700	1.75	14.58	13.804
17	25	200	20	600	1.5	9.1	19.224
18	24	600	20	600	1.5	7.65	18.636
19	1	400	10	600	1.5	2.65	20.241
20	28	400	30	600	1.5	9.65	23.593
21	18	400	20	400	1.5	9.25	21.23
22	4	400	20	800	1.5	8.25	14.713
23	27	400	20	600	1	7.31	18.04
24	7	400	20	600	2	18.51	13.398
25	14	400	20	600	1.5	6.65	17.845
26	30	400	20	600	1.5	6.85	19.98
27	17	400	20	600	1.5	7.12	19.99
28	15	400	20	600	1.5	8.43	13.12
29	16	400	20	600	1.5	9.75	13.25
30	19	400	20	600	1.5	7.12	15.22

III. PROCEDURE FOR RESPONSE SURFACE METHODOLOGY (RSM)

In RSM, it is possible to represent independent process parameters in quantitative form as:

$$Y = f(X_1, X_2, X_3, \ldots X_n) \pm \varepsilon \qquad (1)$$

where, Y- is the response (yield), f-is the response function, ε -is the experimental error, and X_1, X_2, X_3, . . ., X_n are independent parameters. By plotting the expected response of *Y*, a surface, known as the response surface is obtained. The form of "f" is unknown and may be very complicated. Thus, RSM aims at approximating "f" by a suitable lower ordered polynomial in some region of the independent process variables. If the response can be well modeled by a linear function of the independent variables, the function (Eqn. 1) can be written as:

$$Y = C_0 + C_1X_1 + C_2X_2 + \ldots + C_n X_n \pm \varepsilon \qquad (2)$$

However, if a curvature appears in the system, then a higher order polynomial such as the quadratic model (Eqn.3) may be used,

$$Y = C_O + \sum_{i=1}^{n} C_i X_n + \sum_{i=1}^{n} d_i X_i^{\,2} \pm \varepsilon \qquad (3)$$

The objective of using RSM is not only to investigate the response over the entire factor space, but also to locate the region of interest where the response reaches its optimum or near optimal value. By studying carefully the response surface model, the combination of factors, which gives the best response, can then be established. The EDM process is studied with a standard L30 orthogonal array [8]. In this investigation,30 experiments based on orthogonal arrays are conducted at the stipulated conditions based on the procedure mentioned already. The MINITAB software is used for regression and graphical analysis of the data obtained. The optimum values of the selected variables are obtained by solving the regression equation and by analyzing the response surface contour plots. The response surface methodology is a sequential process and its procedure can be summarized as shown in Fig.5.

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The modeling is carried out in the following steps [9]

(i) Identifying the important process control variables and finding their upper and lower limits.
(ii) Developing the design matrix.
(iii) Conducting the experiments as per the design matrix.
(iv) Recording the response parameters.
(v) Developing quadratic models and calculating the regression coefficients.
(vi) Checking the adequacy of models.
(vii) Testing the significance of coefficients and arriving at the final models.
(viii) Presenting the direct and interaction effects of process parameters on MRR and Ra in graphical form.
(ix) Analysis of results.

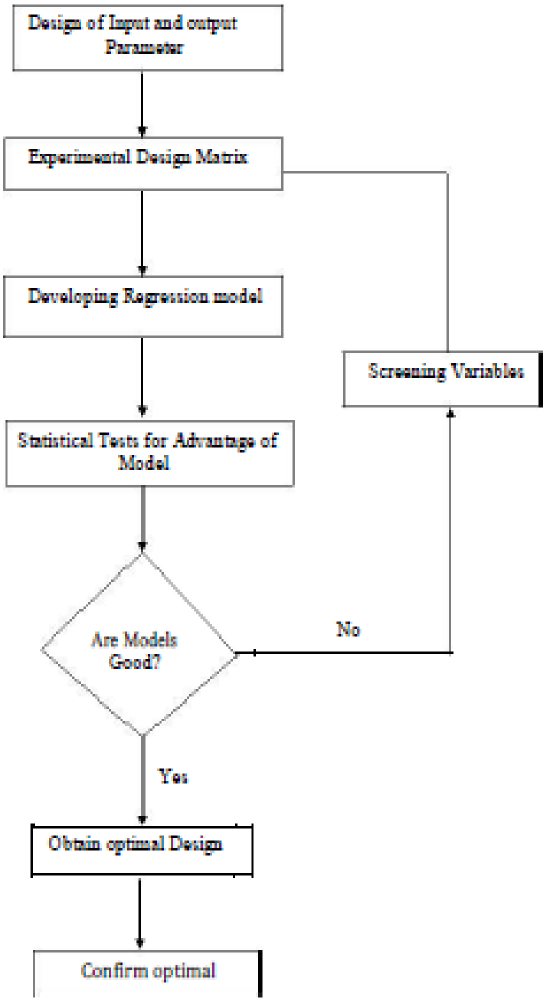

Fig.6.Procedure of Response Surface Methodology

IV. RESULTS AND DISCUSSION

A. Modeling of EDM Characteristics on WC-5Ni Composites

The experiments are conducted according to L30 central composite full design and the average values of MRR and Ra along with design matrix are tabulated in Table III. For analysis of the data, the checking of goodness of fit of the model is very much required. The model adequacy checking includes test for significance of the regression model, test for significance on model coefficients and test for lack of fit. For this purpose, analysis of variance (ANOVA) is performed.

B. Analysis for Material Removal Rate (MRR)

The fit summary recommended that the quadratic model is statistically significant for analysis of MRR. The ANOVA table for the quadratic model for MRR is shown in Table IV. The lack-of-fit term is not significant as it is desired. The results of the quadratic model for MRR are given in Table V The value of R2 is over 90% which means that the regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response (MRR). The associated P-value for the model is lower than 0.05 (i.e.µ = 0.05, or 95% confidence) indicates that the model is considered to be statistically significant[10]. The linear effects of the factor C and P are significant as observed from Table V. The quadratic effect of factor P is more significant when compared to other factors. The interaction effects of factor C with S and P are significant. The result proves that the increase in current enhances the MRR whereas the increase in pulse time reduces the MRR as observed by Luis et al, 2007 [4]. The other model terms are said to be insignificant. Fig.6 displays the normal probability plot of the residuals for MRR. It can be noticed that the residuals are falling on a straight line, which means that the errors are normally distributed and the regression model is fairly well fitted with the observed values. The final response equation for MRR is given in Eqn.4 MRR =7.653-0.189S+1.375C-0.041T+3.491P+0.062SC-0.062ST-0.562SP+0.562CT-1.437CP+0.187TP+0.448S2-0.107C2+0.542T2+1.582P2 (4)

Fig.7 shows the estimated response surface for MRR in relation to the design parameters of peak current and electrode rotation. As can be seen from this figure, the MRR tends to increase, considerably with increase in peak current for any value of electrode rotation. Hence, maximum MRR is obtained at high peak current and high electrode rotation . The increase in MRR is due to the effective flushing of the rotary electrode. When the cylindrical electrode rotates, due to the centrifugal action, a new layer of dielectric fluid will be thrown into the machining gap. This induces a conductive atmosphere for effective discharge and encourages process stability [11]. The enhanced discharge increases the MRR and efficiency. The rate of debris formation is increased at higher peak current, whereas in the case of rotary electrode, a small whirl imparted to the electrode brings about a significant increase in MRR The interaction effect of flushing pressure and peak current on MRR is shown in Fig.8. This figure displays that the value of MRR increases with increase in peak current. The flushing pressure of the dielectric fluid enhances the MRR. With increase in pressure of the dielectric fluid, the MRR tends to increase. This is because the machining performance has been improved since the removed particles in the machining gap are evacuated more efficiently [12]. The maximum MRR is obtained at highest level of peak current (21.91A) and flushing pressure (2Kg/cm2). The maximum possible MRR observed from Fig.7 and Fig.8 is 26.32mg/min. The SEM observation revealed that, with increasing current intensity the working energy increases so that the discharge craters become deeper and wider thus contributing to a more noticeable material debonding from the parent material.

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Table IV: Anova result for MRR (df is degrees of freedom; *F* is Fisher's ratio; *p* is probability)

Source	Sum of squares	df	Mean square	F value	*p*-value(Probability > F)	
Model	459.6777	14	32.83412	13.6096	< 0.0001	signi.
S	0.858817	1	0.858817	0.35597	0.5596	
***C**	45.375	1	45.375	18.8078	0.0006	signi.
T	0.041667	1	0.041667	0.01727	0.8972	
***P**	292.6017	1	292.6017	121.282	< 0.0001	signi.
S × C	0.0625	1	0.0625	0.02590	0.8743	
S × T	0.0625	1	0.0625	0.02590	0.8743	
S × P	5.0625	1	5.0625	2.09839	0.1680	
C × T	5.0625	1	5.0625	2.09839	0.1680	
***C × P**	33.0625	1	33.0625	13.7043	0.0021	signi.
T × P	0.5625	1	0.5625	0.23315	0.6362	
S^2	5.528601	1	5.528601	2.29159	0.1509	
C^2	0.315744	1	0.315744	0.13087	0.7226	
T^2	8.078601	1	8.078601	3.34856	0.0872	
***P**^{2}	68.70763	1	68.70763	28.4791	<0.0001	signi.
Residual	36.18834	15	2.412556			
Lack of Fit	28.96821	10	2.896821	2.00607	0.2289	not signif
Pure Error	7.220133	5	1.444027			
Corrected total	495.866	29				
Std. Dev.	1.553241		R^2	0.94702		
Mean	9.627		Adjus.R^2	0.92890		
C.V. %	16.13421		Predic.R^2	0.91253		
PRESS	177.2539		Adequac Precision	16.5629		

* Significant factor

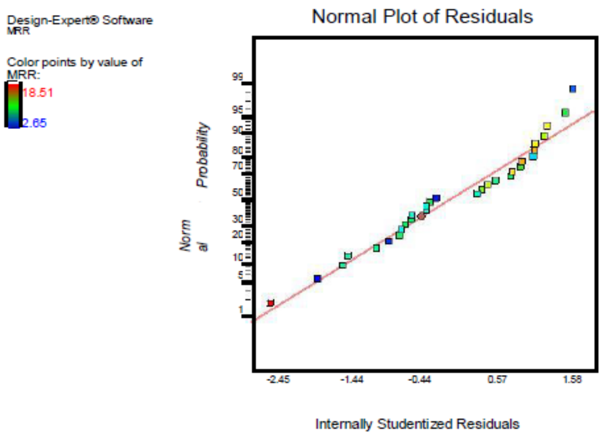
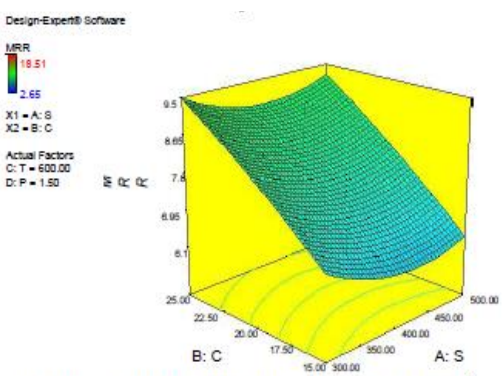
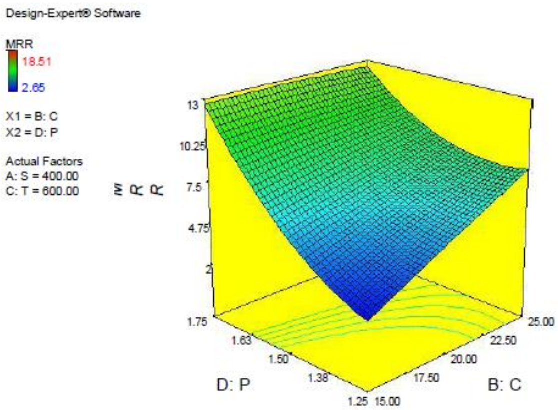


Fig.6 Normal probability plot residuals for MRR of WC-5Ni composite



[Hold Values: Pon (T) = 600 µs, Pressure (P) = 1.5 Kg/cm2]

Fig.7 Effect of peak current and electrode rotation on MRR



[Hold Values: Speed (S) = 400 rpm, Pon (T) = 600 µs]

Fig.8 Effect of peak current and flushing pressure on MRR

Table V: Significance of coefficients for the response model MRR

Factor	*Coeff*	*Coeffestimate*	*Lower bound95%CI*	*Upper bound95%CI*	*df*	*Standarderror*	*t - value*	*p > |t|*
Intercept	bo	7.6533	6.3018	9.0049	1	0.6341	12.0695	<0.0000
S	b_1	-0.1892	-0.8650	0.4866	1	0.3171	-0.5966	0.5591
***C**	b_2	1.3750	0.6992	2.0508	1	0.3171	4.3368	0.0005
T	b3	-0.0417	-0.7175	0.6341	1	0.3171	-0.1314	0.8971
***P**	b_4	3.4917	2.8159	4.1675	1	0.3171	11.0128	<0.0000
***S × C**	**b12**	0.0625	-0.7652	0.8902	1	0.3883	0.1610	0.0015
S × T	b13	-0.0625	-0.8902	0.7652	1	0.3883	-0.1610	0.8741
S × P	b14	-0.5625	-1.3902	0.2652	1	0.3883	-1.4486	0.1668
C × T	b23	0.5625	-0.2652	1.3902	1	0.3883	1.4486	0.1668
***C × P**	**b24**	-1.4375	-2.2652	-0.6098	1	0.3883	-3.7019	0.0019
T × P	**b34**	0.1875	-0.6402	1.0152	1	0.3883	0.4829	0.6357
S^2	**b11**	0.4490	-0.1832	1.0811	1	0.2966	1.5138	0.1496
C^2	**b22**	-0.1073	-0.7394	0.5248	1	0.2966	-0.3618	0.7223
T2	b33	0.5427	-0.0894	1.1748	1	0.2966	1.8299	0.0860
*P2	b44	1.5827	0.9506	2.2148	1	0.2966	5.3366	0.0001

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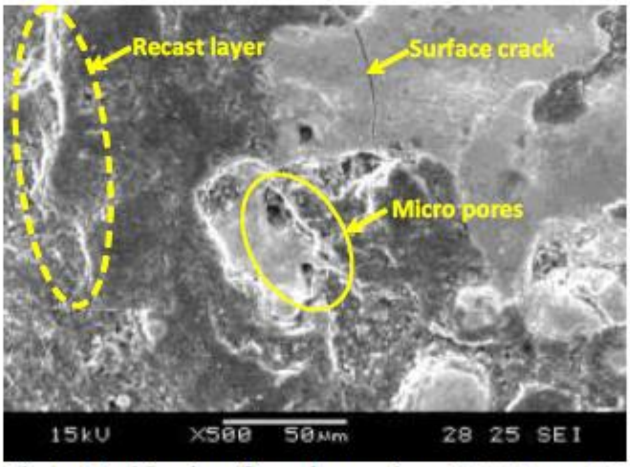

Fig.9. Machined surface observed at : S=200rpm, C= 21.91A, T=400 µs and P =2Kg/cm^2

The sem Fig.9 Reveals the occurrence of a recast layerexhibiting droplets and voids, together with micro-cracks, distributed randomly on the electro discharge machined surface. These phenomena point out that theWC–5wt%Ni alloy is initially molten and/or evaporated by the sparking heat during EDM[13,14]. Most molten and oxidized material is flushed away by dielectric fluid, where as a small amount of molten material is not expelled but rapidly quenched by the dielectric fluid and re-solidifies on the EDM surface to form clustered droplets. This resolidifying material simultaneously shrinks after sparking due to the dielectric fluid cooling. Regions where molten material is re-solidified later on do not have enough molten material to fill in, leading to cavities. Micro- cracks are formed in the recast layer owing to the thermal impact of die sinking EDM[15,16]

A. Analysis for Surface Roughness (Ra)

The ANOVA table for the quadratic model for Ra is shown in Table VI. The model results indicate that the model is significant and the lack of fit is insignificant. The fit summary recommended that the quadratic model is statistically significant for analysis. The value of R_2 is 90% and the associated P-value for the model is lower than 0.05 (i.e. µ = 0.05, or 95% confidence), which indicates that the model is considered statistically significant. Further, linear and quadratic effects of factor C are significant.

Table VII presents the t-test statistics for the quadratic model for Ra. The interaction effects of factor C with S and P are significant and the other interaction effects are insignificant. The result proves that the electrode rotation and flushing pressure enhance the surface finish.

Fig.10 displays the normal probability plot of the residuals for Ra. It is observed that the residuals are falling on a straight line which means that the errors are normally distributed and the regression model is fairly adequate. The response equation for Ra is given in Eqn.5

$$Ra = 16.567 - 0.403S + 1.246C - 0.452T - 1.026P + 0.584SC - 1.415ST + 0.459SP - 0.584CT - 1.709CP - 1.209TP + 0.596S_2 + 1.342C_2 + 0.356T_2 - 0.206P_2 \quad (5)$$

Table VI. ANOVA result for Ra (df is degrees of freedom; *F* is Fisher's ratio; *p* is probability)

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Residual	36.18834	15	2.412556			
Lack of Fit	28.96821	10	2.896821	2.00607	0.2289	not signif
Pure Error	7.220133	5	1.444027			
Corrected total	495.866	29				
Std. Dev.	1.553241		R^2	0.94702		
Mean	9.627		Adjus.R^2	0.92890		
C.V. %	16.13421		Predic.R^2	0.91253		
PRESS	177.2539		Adequac Precision	16.5629		

Factor	Coefficients	Coefficient estimate	Lower bound 95% CI	Upper bound 95% CI	df	Standard error	*t* - value	p > |t|
Intercep	b_0	16.567	14.3016	18.8334	1	1.0631	15.5842	<0.0000
S	b_1	-0.4032	-1.5361	0.7298	1	0.5315	-0.7585	0.4592
*C	b_2	1.2469	0.1139	2.3799	1	0.5315	2.3458	0.0322
T	b_3	-0.4528	-1.5858	0.6801	1	0.5315	-0.8519	0.4068
P	b_4	-1.0263	-2.1592	0.1067	1	0.5315	-1.9307	0.0714
S × C	b_{12}	0.5849	-0.8027	1.9725	1	0.6510	0.8984	0.3823
S × T	b_{13}	-1.4151	-2.8027	-0.0275	1	0.6510	-2.1737	0.0451
S × P	b_{14}	0.4599	-0.9277	1.8475	1	0.6510	0.7064	0.4901
C × T	b_{23}	-0.5848	-1.9723	0.8028	1	0.6510	-0.8982	0.3824
*C × P	b_{24}	-1.7098	-3.0973	-0.3222	1	0.6510	-2.6263	0.0183
T × P	b_{34}	-1.2098	-2.5973	0.1778	1	0.6510	-1.8583	0.0816
S^2	b_{11}	0.5960	-0.4638	1.6558	1	0.4972	1.1987	0.2481
*C^2	b_{22}	1.3428	0.2830	2.4026	1	0.4972	2.7006	0.0158
T^2	b_{33}	0.3564	-0.7034	1.4162	1	0.4972	0.7168	0.4838
P^2	b_{44}	-0.2067	-1.2665	0.8531	1	0.4972	-0.4158	0.6831

Fig.11 shows the estimated response surface for Ra in relation to the design parameters of peak current and electrode rotation. As can be seen from this figure, the Ra tends to increase considerably up to the peak current. With increased peripheral speed of the electrode, the ignition time delay increases, thus bringing down the energy transferred through the individual discharges for material removal. This diminishes the crater dimensions to give a better roughness value [15].

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The machining rate is proportional to the current intensity. High amperage generally requires large machining area and produces greater surface roughness. This will be observed at high peak current and long pulse on time, the reason for the larger roughness values with higher pulse duration can be explained by the generation of the large craters due to large amount of energy [6,5]. The surface contains larger craters and cracks, which would result in poor surface finish. The Fig.12 displays that the value of Ra increases with increase in peak current at least up to its maximum level, and it tends to decrease for high value of the flushing pressure. Along with increased flushing pressure the surface roughness is improved gradually for all current values with certain levels after that it will decrease[6].

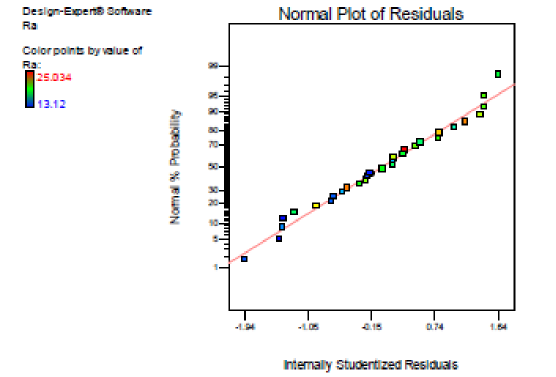
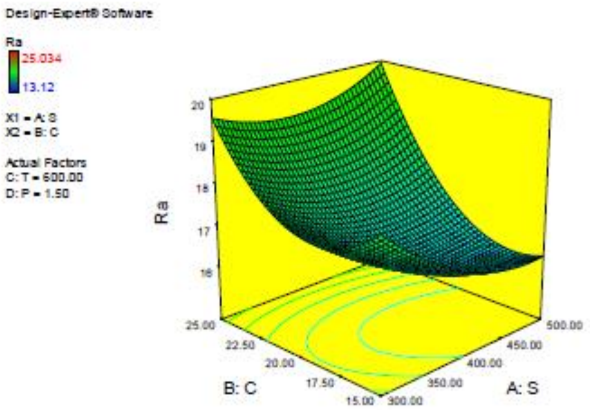


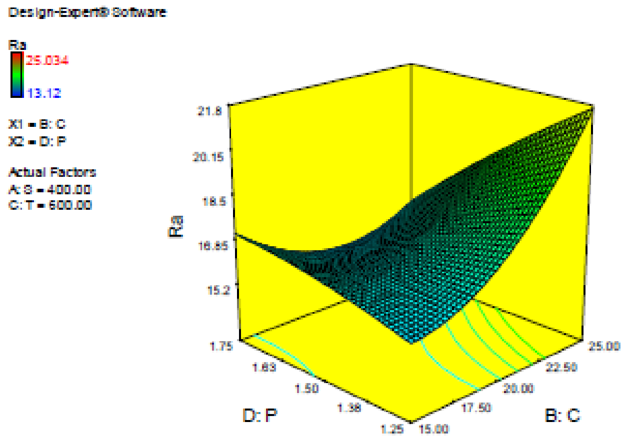
Fig.10 Normal probability plot residuals for Ra of WC-5Ni composite



[Hold Values: Pon (T) = 600 µs, Pressure (P) = 1.5 Kg/cm^2]

Fig.11 Effect of peak current and speed on Ra

The least possible surface roughness of 11.07 µm have been achieved in the following experimental conditions: S=200rpm, C= 21.91A, T=400 µs and P =2Kg/cm^2 . It is observed in the SEM observation of Fig.13. The error between experimental and predicted values for MRR and Ra lie within 5%. Obviously, this confirms the reproducibility of the experimental conclusions.



[Hold Values: Speed (S) = 400 rpm, Pon (T) = 600 µs]

Fig.12 Effect of peak current and pressure on Ra

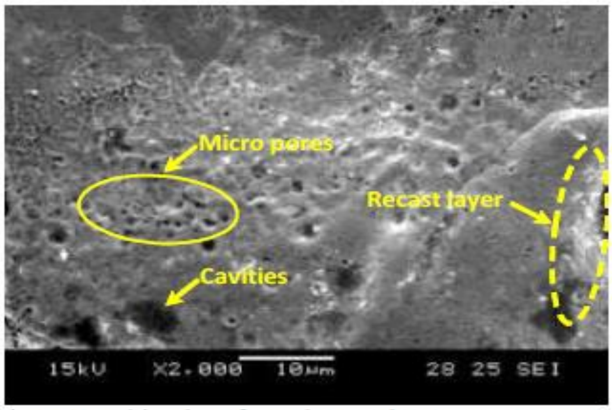


Fig.13 Machined surface observed at : S=200rpm, C= 21.91A, T=400 µs and P =2Kg/cm^2

V. OPTIMISATION BASED ON RSM

Optimisation of the process parameters has been carried out using RSM optimisation technique. Desirability for the whole process optimisation has been calculated to show the feasibility of optimisation, i.e., to explore whether all the parameters are within their working range or not. The goal was to maximise the MRR and minimise the Ra while both are considered at a time.

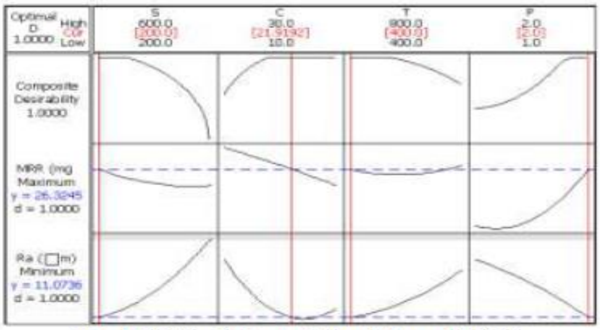


Fig.14 Optimal chart obtained through RSM

The composite desirability is close to one. Fig.15 exhibits optimisation plot for the both responses. The optimum values from the plot are MRR = 26.32 gm/min and Ra = 11.07µm and the relevant parameters electrode rotation, current, pulse on time, flushing pressure are 200rpm,21.91A,400 µs,2kg/cm^2 respectively.

VI. CONCLUSION

The effect of current (C), pulse on time (T), electrode rotation speed(S) and flushing pressure (P), in the die sinking EDM has enhanced the rate of material removal and improved the surface finish of WC/5Ni composites.

Empirical modeling with the help of response surface methodology has led to the following conclusions abou the variation of response parameters in terms of independent parameters within the specified range.

The rotation of electrode and flushing pressure of the dielectric fluid of EDM affect both MRR and Ra. The MRR increases with the increase in the rotation of the electrode and flushing pressure. Therefore more improvement in MRR is expected at still higher level of electrode rotation and flushing pressure of die electric fluid. The improvement in surface finish is also expected at higher level of electrode rotation and flushing pressure of die electric fluid. It would be observed as the S=200rpm, C= 21.91A, T=400 μs and P=2Kg/cm_2

The MRR is maximum for all compositions. As the percentage of nickel increases the thermal conductivity of the composition increases since the nickel material is easily removed from the surface of the parent material. So the MRR increases with percentage of nickel.

The surface roughness increases with increase in current and flushing pressure irrespective of %Ni. The optimum Ra values decreased with increasing electrode rotation. Due to With increased peripheral speed of the electrode, the ignition time delay increases, thus bringing down the energy transferred through the individual discharges for material removal. This diminishes the crater dimensions to give a better roughness value.

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