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Optimizing WEDM Parameters for Machining of Nimonic-80A alloy using RSM Technique

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Abstract

This paper presents the experimental investigation to optimize the WEDM parameters for the effective machining of Nimonic-80A alloy using RSM technique. To determine the optimum machining parameters of WEDM affecting the machining performance of Material removal rate and Surface roughness, the RSM technique is used. The machining results were obtained by variation of input peak current ranging from 50 to 150 Amp, gap voltage ranging from 10to80Volts, duty cycle ranging from 10 to 100µs, and wire speed from 4to10mm/min. Regression equations and models are developed using the Anova analysis for determining the significant machining parameters affecting the output responses. The multi response optimizations using the desirability function for MRR and SR for machining of Nimonic-80A Alloy by WEDM is I_P 63Amp, G_V 80 Volts, DS 77µs, and WS 4 mm/min of wire electrode. The SEM analysis of machining samples at high and low level of parameters was done. There is a significant variation in the crater size of the two samples; at high value deep overlapping craters were created while at low levels craters are small with surface appearing smoother.

Keywords: WEDM, Nimonic 80-A, MRR, SR, RSM, Multi response optimization.

Nomenclature

WEDM	Wire EDM
Ip	Peak Current (Amp)
Gv	Gap Voltage (v)
DS	Duty Cycle (µs)
WS	Wire Speed (mm/min)
MRR	Metal Removal Rate (mm3/min.)
SR	Surface Roughness (Ra)
Ra	Arithmetic mean roughness (µm)
ANOVA	Analysis of Variance
RSM	Response Surface Methodology

INTRODUCTION

Nimonic alloys typically consist of more than 50% nickel and 20% chromium with additives such as titanium and aluminum. Nimonic alloys are extensively used for the manufacturing of aero engine components, and hot combustion chamber of gas turbines because of its high specific strength (strength to weight ratio), which is maintained at higher temperature. High hard alloys are the need of manufacturing companies, but with the limited scope of machining with traditional manufacturing process. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, Electrical Discharging Machine (EDM) etc. are applied to machine such difficult to machine materials. The wire electric discharge machining is a variation of EDM and is commonly known as wire-cut EDM or wire cutting. In this process, a thin metallic wire is fed on-to the work piece, which is submerged in a tank of dielectric fluid such as de-ionized water. During machining of WEDM, the mechanical stresses are eliminated resulting in easy machining of hard alloys.

(Sreenivasa & Venkaiah, 2015). investigated the machining of Nimonic-263 alloy of WEDM using RSM and PSO. Using ANOVA, it was found that pulse on time, peak current and servo voltage were the significant parameters affecting MRR and Surface finish. The best possible solutions were compared from PSO and RSM. RSM was found better than PSO. (Choudhary et al., 2015) research on surface roughness of Nimonic 75 alloy for EDM parameters peak current and pulse on-time were investigated using Taguchi's design methodology. Increase in pulse on time also accounts for higher surface roughness. Energy delivered in single spark increases with increase in pulse on-time causes increased size of craters on the machined surface. (Gosawmi & Kumar, 2014) did experimental study for Nimonic-80A for optimizing the material removal rate and wire wear ratio by using taguchi design optimization on WEDM process. Relationships were found between peak current and pulse on time, pulse off time and gap voltage. The study shows that material removal rate increases with the increase in pulse-on time and peak current. It is supported with SEM micrograph showing deep craters at high peak current and pulse on time.

(Jangra et al., 2014) study of rough and trim cutting operation in, wire electric discharge machining is presented on four hard to machine materials WC-Co composite, HCHCr steel alloy, Nimonic 90 and Monel- 400. The machining speed is lowest in WC-Co composite while nickel alloys, Nimonic 90 and Monel -400 shows increase in machining speed with increase in discharge energy. (Kumar et al., 2013) investigated on WEDM of pure titanium using response surface technique for optimizing the responses of surface roughness and dimensional deviation. The F-test analysis shows that pulse on time, pulse off time, peak current are the main factors affecting the response variables. (Muthuraman et al., 2012) in the research of Wire electro discharge machining (WEDM) to machine tungsten carbide–cobalt (WC-CO) metal matrix composite, recommended that keeping the off-time at 15µ sec, the on-time at 8µsec and ignition- current at 16 A the output response MRR can be maximized. (Sharma et al**.,** 2012) in the experimental study of High strength low-alloy steel (HSLA) examined the parameters of Pulse on time (Ton) and Pluse off time (Toff) for cutting speed and dimensional deviation on WEDM. (Kumar et al., 2012) investigated for Nimonic-90 the affect of current (Ip), pulse on time (Ton), and servo voltage (SV) on WEDM set up for cutting speed. Increase in current results in high cutting speed but with too much increase the debris in the spark gap, resulting in arcing. The servo voltage increase, favours the cutting speed but with high increase leads to large amount of debris resulting in unstable machining of it.

The literature review shows WEDM process is the finest non-conventional machining process to machine intricate shapes for hard materials with great accuracy. The research indicates peak current, pulse on time, pulse off and gap voltage are the significant parameters affecting machining output responses of MRR, surface finish and wire wear ratio for Nimonic alloys. In the precited literature review the machining research of Nimonic-80A alloy is very little. Few works with limited range of parameters using taguchi design focusing on MRR and wire wear ratio have reported. There is need to optimize the process parameter of WEDM to provide a sufficient data to the machinist for increasing the machinabilty of Nimonic-80A alloy. The current study investigates the machining of Nimonic-80A alloy with RSM approach using a different range of parameters peak current, duty cycle, gap voltage and wire speed to increase the MRR and surface finish.

EXPERIMENTATION

Wire Electrical discharge machining is to be used for the experimental investigation. Nimonic 80 Alloy will be used as work piece material. Experiments will be conducted based on RSM with four factors at three levels each for the input parameters peak current, gap voltage and duty cycle and wire speed of WEDM. The various performance criteria of WEDM machining, which are considered for optimizing the WEDM parameters for maximum of material removal rate, and lower of surface roughness. Nimonic 80A (77.05%, Ni, 18.39% Cr, 1.92% Ti, 1.05% Al, 0.63% Fe, 0.2% Mn, 0.19% Si) sheet of thickness 3 mm was used as work material. Specimens (Rectangular) of size 5mm×5mm× 3mm were machined from the sheet using brass wire electrode of diameter 0.25 mm. De-ionized water was used as the dielectric fluid. The set of 29 experiments were performed using the input data of parameters and time for each experiment was recorded using a stop watch. After the machining the MRR of all the specimens were calculated with VMRR method

VMR = Kerf width × thickness of plate × cutting length for each specimen × 4

VMRR = VMR (mm³) / time (minutes) for each experiment.

Surface roughness of the specimens was measured using the talysurf roughness tester 3 times with cut off length of 0.8mm with average R_a considered.

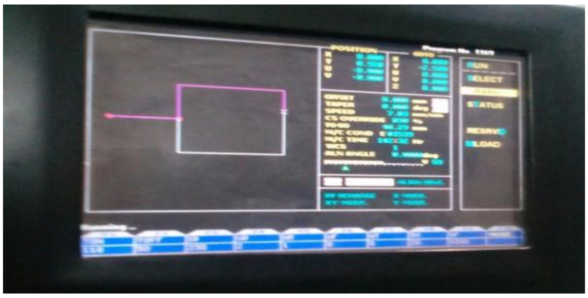

Figure 1 (a) Machining Profile of Work piece on WEDM

Figure 1 (a) Surface Roughness measuring using Talysurf-surface roughness tester

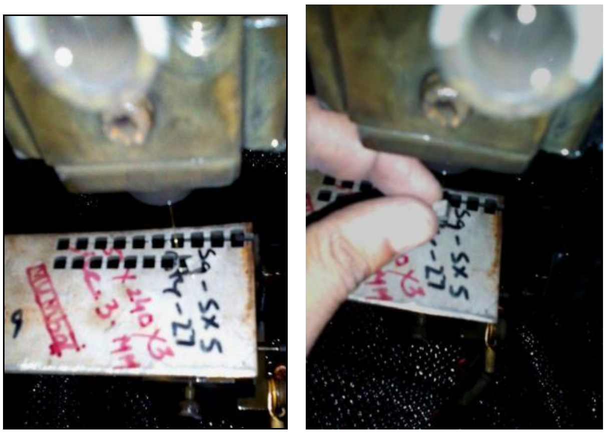

Figure 2. Work piece after experiments

RESULTS AND DISCUSSIONS

Table 1.2 shows the values of the response factors for MRR and Surface finish for the different combination of the machining parameters. The MRR value is in the range of (5.64-19.56) mm³/min with surface roughness (1.1-3.2)µm. Design of Expert software is utilized to conduct the experimentations as per RSM technique. Box Behnken designs was selected for determining the significant parameters using ANOVA and calculating the mathematical model for machining output responses of MRR and surface finish.

Table 1.1 Parameter Control factors and their Ranges

Coded Factor	Parameter Name	Unit	Symbol	Lower Limit	Upper Limit
A	Peak Current	(Amp)	Ip	50	150
B	Gap Voltage	(v)	Gv	10	80
C	Duty Cycle	(µs)	DS	10	100
D	Wire Speed	(mm/min)	WS	4	10

Table 1.2 Box Behnken design with output responses

Run	Peak Current(Amp)	Gap Voltage(v)	Duty Cycle(µs)	Wire speed(mm/min)	VMRR=mm^3/min	SR=Ra
1	100	80	10	7	14.36	1.68
2	150	45	55	10	15.32	2.36
3	50	45	10	7	5.64	1.21
4	100	45	100	4	10.61	2.23
5	100	80	55	10	15.42	1.54
6	100	45	55	7	11.36	1.36
7	100	45	100	10	11.46	2.21
8	100	45	55	7	11.36	1.89
9	150	80	55	7	19.56	3.21
10	150	10	55	7	13.57	2.15
11	100	45	10	10	11.75	1.26
12	100	80	55	4	15.45	1.54
13	100	45	55	7	12.76	1.15
14	100	45	55	7	12.82	1.16
15	150	45	10	7	16.28	2.72
16	150	45	55	4	17.12	3.23
17	50	45	100	7	8.31	1.13
18	100	10	100	7	12.87	2.14
19	100	10	55	4	11.25	1.12
20	50	80	55	7	8.36	1.10
21	100	10	55	10	9.1	1.68
22	50	10	55	7	9.36	1.78
23	150	80	100	7	19.92	3.23
24	100	45	10	4	9.23	1.45
25	100	80	100	7	15.81	2.2
26	100	45	55	7	12.84	1.58
27	50	45	55	10	9.46	1.03
28	50	45	55	4	8.83	1.03
29	100	10	10	7	9.67	1.11

ANOVA for MRR

The table 1.3 shows the ANOVA for MRR. The mathematical equation obtained by regression analysis using the experimental data is listed below:

*MRR = 4.56019 + 0.041414 * Peak Current - 0.044738 * Gap Voltage + 0.022296 * Duty Cycle + 9.98571E – 004 * Peak current * Gap Voltage …………………eq(1)*

Table 1.3: ANOVA for MRR

ANOVA for Response Surface Reduced 2FI Model						
Analysis of Variance Table [Partial Sum of Squares]						
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**	
Model	292.65	4	73.16	41.06	< 0.0001	Significant
A	223.69	1	223.69	125.53	< 0.0001	
B	44.66	1	44.66	25.06	< 0.0001	
C	12.08	1	12.08	6.78	0.0156	
AB	12.22	1	12.22	6.85	0.0151	
Residual	42.77	24	1.78			
Lack of Fit	40.25	20	2.01	3.20	0.1337	Not significant
Pure Error	2.51	4	0.63			
Cor Total	335.41	28				

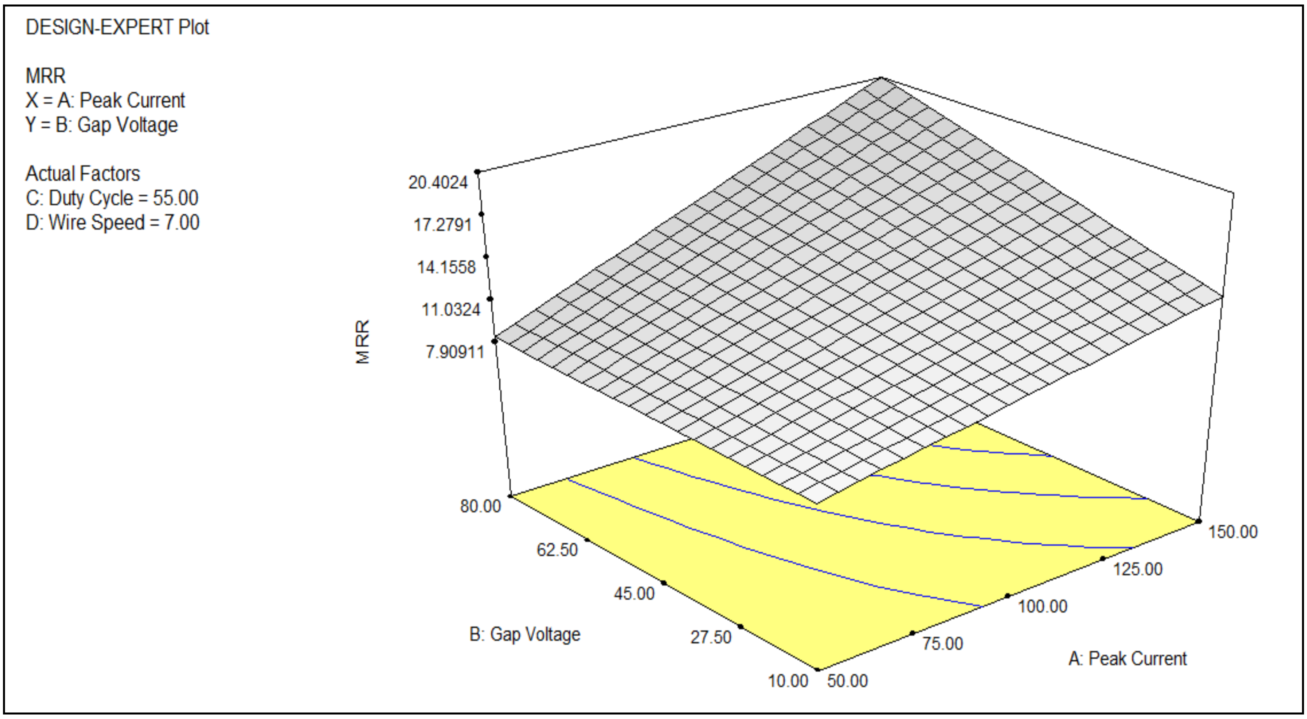

Figure 3: Peak Current and Gap voltage vs MRR

The Model F-value of 41.06 implies the model is significant. Values of "Probability > F" less than 0.05 indicate model terms A, B, C and AB are significant. In this case peak current(A) is the most significant parameters affecting MRR. This model can be used to navigate the design space.

The Figure 3 shows the 3–dimensional plot shows interaction of Peak current and Gap voltage with MRR. MRR increases very fast with increase in current from 50 to 150 Amp, but a very slight increase in MRR with increase in voltage from 10 to 80V showing that peak current is the most significant parameter affecting MRR.

ANOVA for Surface Roughness

The Table 1.4 shows ANOVA for surface roughness. The mathematical equation obtained by regression analysis using the experimental data is listed below:

*SR = 2.61452 – 0.030303 * Peak Current - 0.021795 * Gap Voltage – 6.17654E - 003 * Duty Cycle + 1.75673E - 004 * Peak current^2 + 1.18608E - 004 * Duty Cycle^2 + 2.48857E - 004 * Peak Current * Gap Voltage……………………………….…….eq (2)*

Table 1.4: ANOVA for Surface Roughness.

ANOVA for Response Surface Reduced Quadratic Model						
Analysis of Variance Table [Partial Sum of Squares]						
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**	
Model	11.31	6	1.89	24.19	< 0.0001	Significant
A	7.71	1	7.71	98.89	< 0.0001	
B	0.14	1	0.14	1.80	0.1933	
C	1.15	1	1.15	14.71	0.0009	
A^2	1.33	1	1.33	17.08	0.0004	
C^2	0.40	1	0.40	5.11	0.0341	
AB	0.76	1	0.76	9.73	0.0050	
Residual	1.72	22	0.078			
Lack of Fit	1.33	18	0.074	0.76	0.7006	Not significant
Pure Error	0.39	4	0.097			
Cor Total	13.03	28				

The Model F-value of 24.19 implies the model is significant. Values of "Prob > F" less than 0.05 indicate model terms A, B, C, A^2, C^2 and AB are significant. In this case Peak current(A) is the most significant parameters affecting surface roughness. This model can be used to navigate the design space.

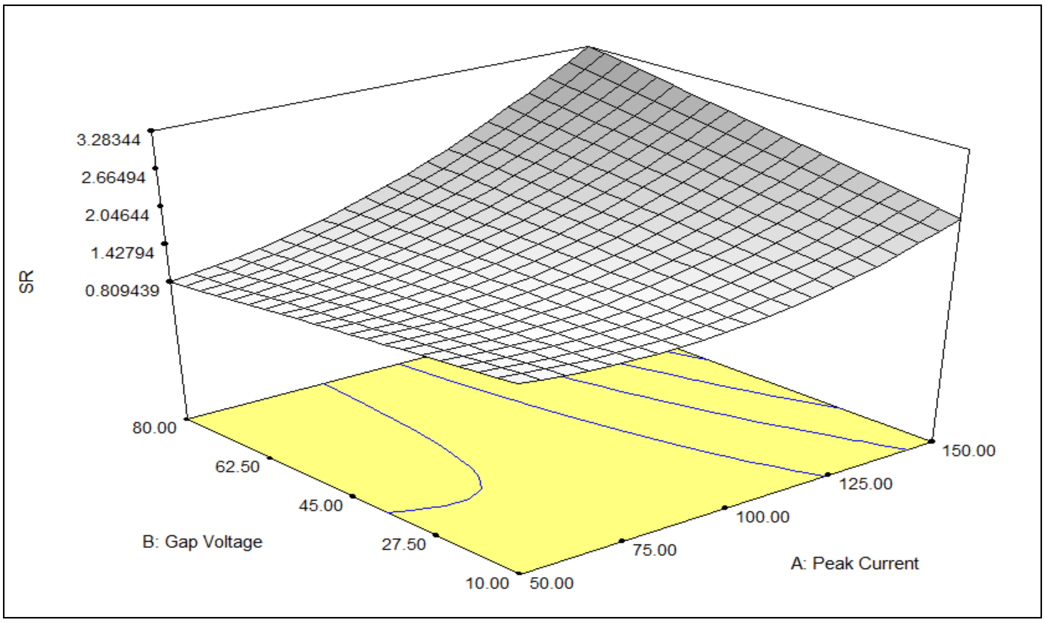

Figure 4: Peak Current and Gap voltage vs SR

The Figure 4 shows the 3–dimensional plot shows interaction of Peak current and Gap voltage with SR. SR increases gradually with increase in current from 50 to 150 Amp, but a very small change in SR with increase in voltage from 10 to 80V showing that peak current is the most significant parameter affecting SR.

Normality Test for Conforming the Validity of the Model for MRR and SR

The equations (1) and (2) for MRR and surface roughness are used for generating the predicated values against the measured experiment values for the different combinations of machining parameters in Table 1.3

The figure 5(a) and 5(b) shows for MRR and surface roughness most of residuals are found on a straight line which indicates that errors are normally distributed confirming the validity of the model.

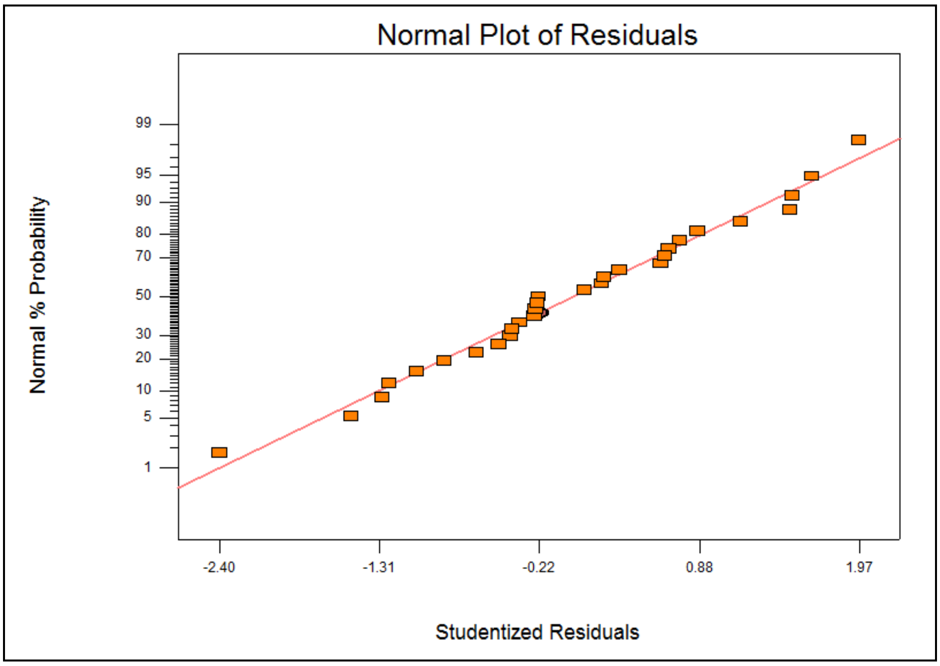

Figure 5 (a) Comparison between measured and predicted values for MRR

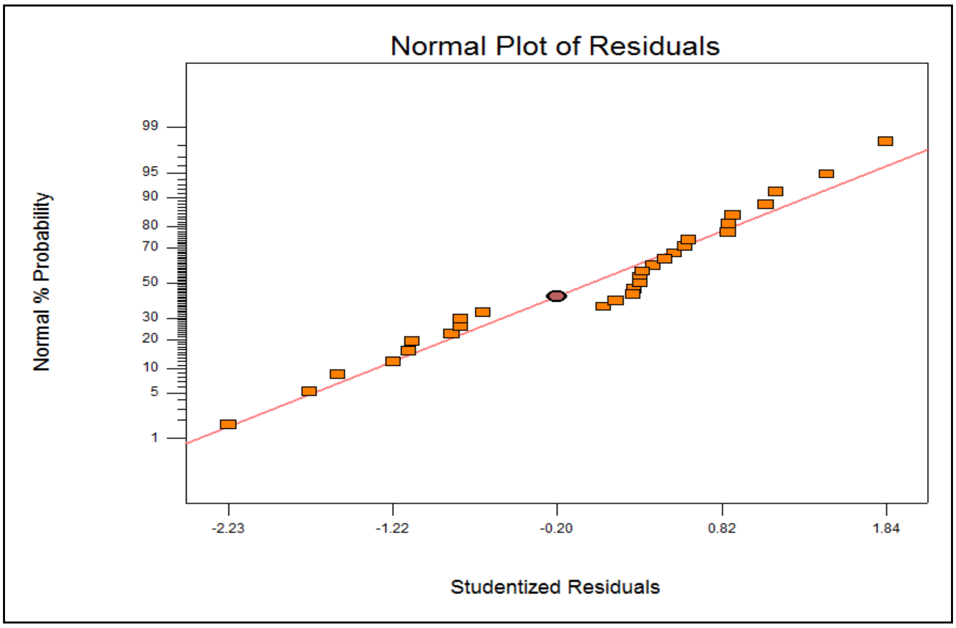

Figure 5 (b) Comparison between measured and predicted values for surface finish

Multi Response Optimization using Desirability Function

Multi response optimization for MRR and surface roughness was carried out using desirability function in conjunction with RSM to overcome the problem of contradictory responses of single response optimization. All possible multi characteristics models have been developed. Goals and limits were established for each response in order to accurately determine their impact on overall desirability.

Table 1.5: Goals and limits for multi response optimization

Constraints						
Name	**Goal**	**Lower Limit**	**Upper Limit**	**Lower Weight**	**Upper Weight**	**Importance**
Peak Current	is in range	50	150	1	1	3
Gap Voltage	is in range	10	80	1	1	3
Duty Cycle	is in range	10	100	1	1	3
Wire Speed	is in range	4	10	1	1	3
MRR	Maximize	5.64	19.92	1	1	3
SR	Minimize	1.032	3.236	1	1	3

Ramp Function graph for desirability:

The ramp function graph for desirability for multi optimization shows the level of response setting for each factor. This is indicated by the dot on each graph of the response.

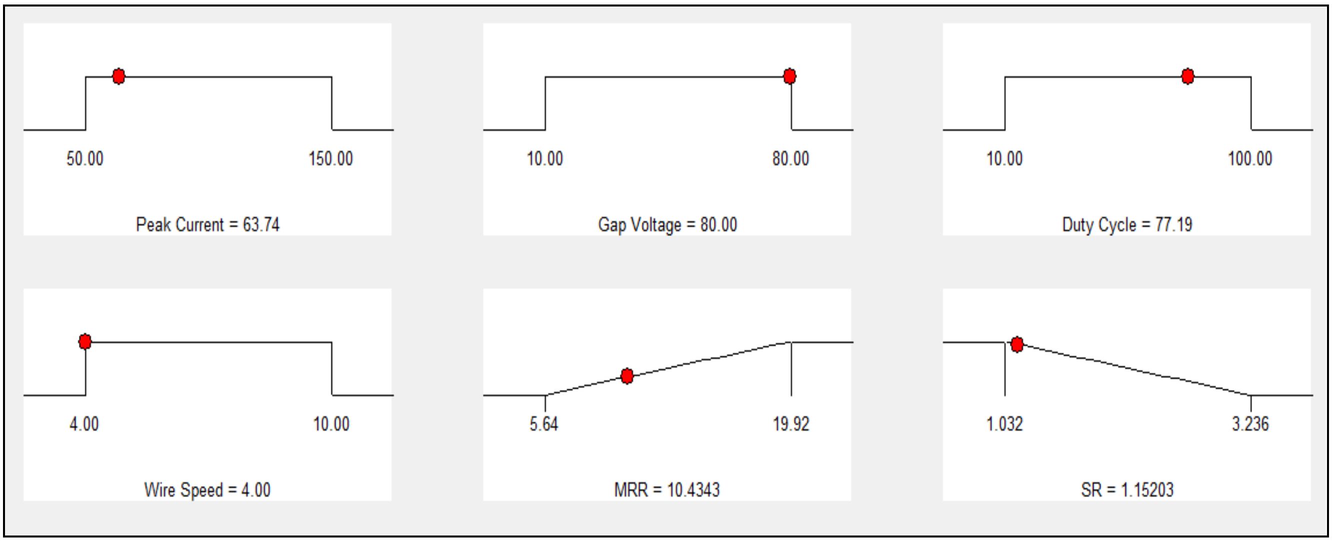

Figure 6: Ramp function graph of desirability for multi optimization

Figure 6 indicates the optimal set of conditions for machining of Nimonic - 80A Alloy by WEDM is I_P 63 Amp, G_V 80 Volts, DS 77µs, and 4 mm/min WS for maximize MRR 10.34 mm^3/min and minimize SR 1.15 R_a under specified constraints selected.

SEM Results of Machined Specimen

The microstructure of machined surface area was analyzed using SEM. The two specimens were selected for microstructure observation with high value of MRR and another with low value of MRR. Figure 7 shows the SEM analysis of machining surface area at higher level of parameters. At higher peak current (150Amp), high electrical discharge energy results in overlapping craters and lump of debris as seen in SEM of the above sample.

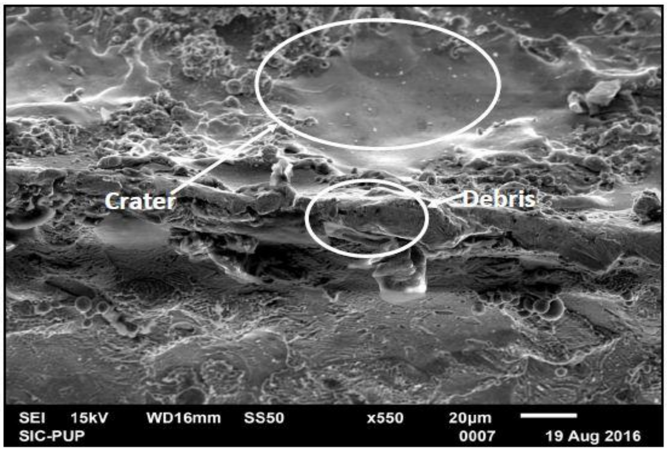

Figure 7: Microstructure of machined sample at high level of parameters

Figure 8 shows the SEM analysis of machining samples at low level of parameters. The machined surface in this case appears to be smoother as discharge craters are extremely small with small amount of debris. There is a significant variation in the crater size, which could be related to the uneven distribution of discharge energy along the surface. The machined surface in this case appears to have a very less density of cracks due to machining at low level of current (50 A).

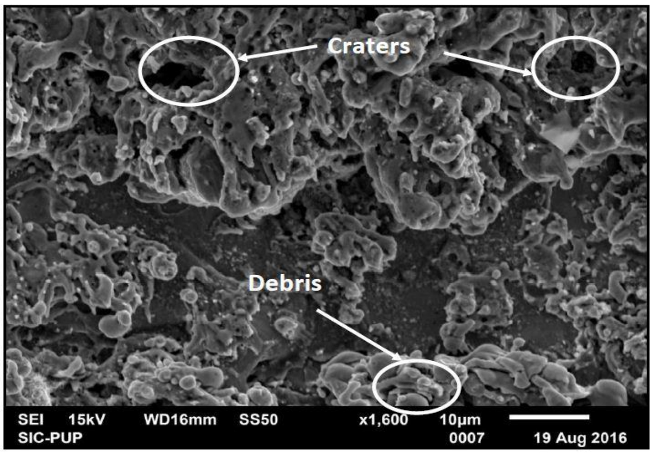

Figure 8: Microstructure of machined sample at low level of parameters

CONCLUSIONS

In present work, the experimental study during the machining of Nimonic Alloy on WEDM a total 29 experiments were conducted using RSM to identify the best possible machining characteristics to maximize the MRR, and minimize the surface roughness. Following are the conclusions drawn from the experimental study.

- ANOVA results shows that Peak current, Gap voltage and Duty cycle are significant parameters affecting MRR. Peak current being the most significant factor affecting MRR.
- ANOVA results shows that Peak current, Gap voltage and Duty cycle are significant parameters affecting surface roughness. Peak current being the most significant factor affecting surface roughness.
- Multi response optimization results for machining of Nimonic 80-A alloy on WEDM is I_P 63Amp,G_V 80 Volts, 77µs DS and 4 mm/min WS with maximizing MRR and minimizing surface roughness.
- SEM results shows for sample with high peak current and high voltage, the discharge energy per pulse increases, which produces the deeper and wider overlapping craters, pockmarks, and cracks on the machined samples. The other sample was machined at low energy input rate of peak current and gap voltage appears to be smoother as discharge craters are extremely small with small amount of debris.

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