Investigating Performance of Wire Electric Discharge Machining of Nimonic 90 and RSM Modeling

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Investigating Performance of Wire Electric Discharge Machining of Nimonic 90 and RSM Modeling

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Abstract: Nimonic nickel-based superalloys are widely used in many industries like aerospace engine components and hot chambers of gas turbines, jet engines, and heat exchangers owing to their high resistance to creep, oxidation, and corrosion. These properties even do not lose at elevated temperatures. Conventional machining methods have various encounters like surface roughness, tool wear rate, tool failures, and surface characteristics. To overcome these challenges, shifting from these traditional processes to non-traditional machining processes is required. Hence, in this study, a Wire Electric Discharging Machine (WEDM) a nonconventional method has been chosen to machine high-hardness material like Nimonic 90 with great precision. WEDM experiments were carried out using CCD with three factors of input. Servo-voltage, Pulse-on time, and tension in the wire are taken as inputs having three different levels consisting of 20 runs based on RSM to analyse the responses such as MRR and SR. A scanning electron microscope (SEM) is used to understand the surface topography of a workpiece whose roughness is more and less and of those with high MRR and Low MRR. On Surface globules, micro-cracks, pits, and debris are observed. Pulse-on and wire tension have more impact on Material removal over servo voltage, whereas for better surface finish Wire tension has more influence than Pulse-on and servo voltage.

Keywords: Nimonic 90; WEDM; RSM; DOE; SEM

1. Introduction

There is a challenging demand for more production with high quality, and there is high competition in the manufacturing industry from customers getting these high-quality products[1)]. In Manufacturing industries, the major concern is to make good quality products with high accuracy in dimension, better surfaces, and less wastage in tools[2)]. For the machining of ceramic materials which are brittle and hard, diamond tools are used which have a low machining rate, and fail to cut complex shapes. To meet such demand from customers and also to high-quality products of precise size and shape for any material including brittle materials, WEDM is used[3)]. In WEDM, the potential between electrodes is high enough to accelerate the electrons toward the workpiece and ionize the dielectric fluid[4)]. As the formation of electrons and ions increase in dielectric fluid, there will be an avalanche motion i.e., low resistance motion. This motion is visualized as electric energy discharge which develops about 10,000º C. This energy is appropriate to liquify and evaporate any conductive material without considering its hardness and strength[5)]. This heat generated between the electrodes is minimized by dielectric fluid flushed at the required pressure through the nozzle between electrodes[6)]. Removal of debris through a narrow slit between electrodes by dielectric fluid leads to short-circuiting and breaking of wire[7)]. The production rate of spark in WEDM is due to parameters like Pulse on, pulse off duration, current, Wire tension, Wire feed, and servo voltage. The duration for which the spark is active between electrodes is called a pulse on, and the duration of an inactive spark is called a pulse off. Wire tension, Wire feed, and servo voltage are important for output responses like surface roughness, material removal, and tool wear[8)]. In WEDM Wire electrode motion is controlled by (CNC) Computerized Numerical control to achieve the required shape on the workpiece, either in two dimension or three-dimensional shape accurately[9)]. Wire electrode is moved with the help of rollers, which are even rolled to maintain tension. Machining in WEDM can be enhanced by setting selected Inputs at optimal values[10)]. Nickel is one of the abundant materials in the earth's crust found in about 0.016% of the earth's crust, and can be alloyed to steel, and high-temperature alloys. Nickel addition improves the toughness and ductile nature of the material[11)]. Nickel superalloy is extensively used in aerospace manufacturing industries because of maintains the same abilities even at high temperatures and stress[12]. Nickel alloys are the backbone for industries like Nuclear, Petrochemical, Steam Plant, submarine, aerospace, and medical fields. Parts like discs, bolts, Vanes, casings, shafts, reciprocating turbo-chargers, hot plugs, combustion chambers, and blades of turbines in aerospace are the main consumers of nickel alloys[13]. Alloys of nickel cannot be machined by Conventional methods even with ceramic or carbide tools, due to its ability to resist heat. The surface of Nickel alloys gets poor surface integrity, and built-up edges[14]. Surface defects like surface cracks, tearing, and pull-out of material are observed while machining using conventional methods which is an immense challenge in the machining of nickel superalloys for the industrial sector[15]. To overcome these difficulties Unconventional machining techniques are used, WEDM is one among them which has wide acceptance in the machining of nickel superalloys[16]. Ashish et. al.,[17] observed an increase in higher discharge causes cracks, voids, and craters when the pulse duration is high. They also concluded roughness of the surface and wear rate in the tool becomes less at a low energy value. S Vellingiri et. al,.[18] has studied the WEDM effect on LM13 and LM13 alloyed with Sic composite, they claimed that material removal rate and surface roughness have a negative influence on each other. They have suggested that for high metal removal pulse on and servo voltage should be high whereas pulse off should be average, for better surface roughness the pulse on time and servo voltage should be less and the pulse off time should be high. M Sreenivasa Rao et al[19] suggested that pulse on time in the range of 105-125 (μs), Pulse off time in a range of 50-60 (μs), Current 10-12 A, and Servo voltage between 40-60(V) are suitable process parameters and can avoid wire breakage and short-circuiting in the wire. Pulse on time, current, and interaction of them have more influence on the rate of material removed and surface roughness through WEDM of nickel superalloys. B Singh and J P Mishra[20] have conducted a WEDM experiment on Nimonic 263 considering Pulse on duration, pulse off duration, peak current, and servo voltage as inputs to identify the influence on wear ratio. Pulse-on has more influence on wear ratio compared to others. The empirical model developed has only a 1% error. Sameh Habib[21] has observed that kerf width is indirectly related to wire tension, and wire feed is directly proportional to the flushing pressure of dielectric and servo voltage.

Many researchers have studied nickel-based superalloys, especially Inconel 718, Inconel 825, Inconel 625, Monel, Nimonic 75, and Nimonic 80. In contrast, very few researches have been done on Nimonic 90 one among the nickel superalloys. Machining of nickel superalloys is a major issue for the industrial sector as it is difficult to machine and obtain better surface quality by conventional methods owing to its properties like low thermal conduction, high hardness, and better strength. Still, these are not constraining for a WEDM machine an unconventional machine. WEDM machine uses the principle of spark theory, which does not consider the hardness of material instead material should be electrically conductive. All conductive materials can be machined in any intricate shape. WEDM uses several electrodes like brass, Zinc coated to brass, molybdenum, and copper which behave as negative electrodes and workpieces as positive electrodes. Dielectric fluid is used for flushing material which is melted and evaporated and also helps not to reduce the temperature around the machining area. Selecting of process parameters is very vital in WEDM, hence Pulse-on time, Servo voltage, and current are considered as inputs with 3 levels taken for machining of Nimonic 90. RSM develops experiments and mathematical modeling of output parameters.

2. Experimentation

Nimonic 90 is used as a workpiece i.e., a positive electrode in the form of a plate of dimension 150mm ×140mm as shown in Fig. 1(a & b). The composition of Nimonic 90 is shown in Table 1.

Fig. 1 (a):

Fig. 1 (b):

Fig. 1(a). & 1 (b): Nimonic 90 plates with dimensions

Table 1. Chemical content in Nimonic 90

Chemical list	% of cont.
Fe-Iron	Max. 58%
Cr- Chromium	Max. 20%
Co-Cobalt	Max.18%
Ti-Titanium	Max. 3%
Al-Aluminium	Max. 2%

Maxi-e cut Wire EDM machine is used to perform experiments as shown in Figure 2, whose technical specification is given in Table 2. Brass wire is used as an electrode of diameter 0.25mm and is used as a negative electrode for machining in WEDM during experimentation. De-ionized water is used as dielectric fluid during experimentation, which even helps in the removal of eroded material as well as it helps in the breakdown of current amongst the Workpiece (positive electrode) and brass wire (negative electrode). WEDM has various input parameters given in Table 3. Among these parameters based on literature pulse-on time, Servo voltage, and Wire tension are considered as inputs presented in Table 4.

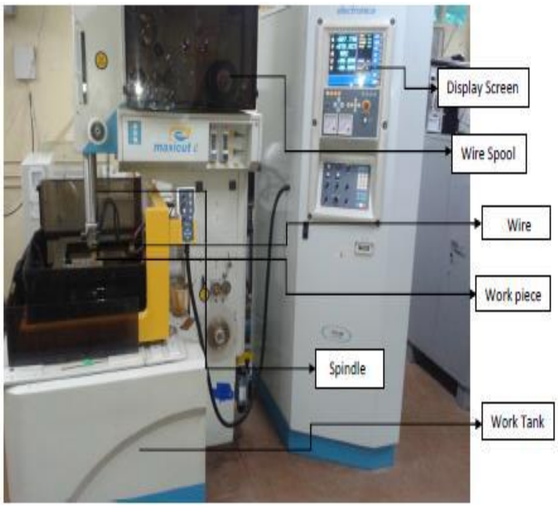


Fig. 2: Maxi-e Cut Wire EDM

Table 2. Specifics of Maxi e cut Wire EDM

Maximum capacity of Table Size	440×650mm
Maximum height	200mm
Maximum Withstanding of Weight	300 (Kg)
Axis of motion	X & Y, U & V
Dia. of used wire	Std-0.25mm, Min (0.15mm), Max. (0.3 mm)
Memory Storage	1000 blocks (Battery Backup)
Capacity of tank	250 (L)
Backup generator	ELPULS-20e
Running-Load	07 Kilo VA
Avg. Power Consum	3.5- 5 (KVA)
Power Input (AC).	3P, 50KHz, 415V

Table 3. Various inputs and their range on Maxi e cut Wire EDM

Various Inputs	Values on Machine
Time of Pulse-on (T_{on})	Max of 131(μs)
Time of Pulse off (T_{off})	Max 63 (μs)
Tension of Wire (WT)	Upto-15 (N)
Servo-Voltage (SV)	Up to 99 (V)
Flushing pressure of Water (WFP)	Max 15 (kg/cm^2)
Feed rate of Wire (WF)	Max 15(mts /min)
Input Current (A)	0-230

Response Methodology helps to design experiments with selected parameters in Minitab software. Using AutoCAD, a square profile of size 10mm×10mm and imported into the

Table 4. Selected parameters and its level

Parameter	Selected Inputs		
	-1	0	1
Pulse-on time (μs)	80	95	110
Servo-Voltage (V)	50	65	80
Wire tension (N)	10	11	12

Maxi e-cut WEDM machine. Outputs i.e., Material Removal (MRR), and Surface-Roughness (SR) are calculated for every experiment. Surface Roughness is measured using the Taylsurf machine and by using below formula given below in equation (1). The material removal is calculated as

$$MRR = \frac{Volume\ of\ material\ removed\ (mm^3)}{Time\ Taken\ for\ cutting\ of\ specimen(s)} \quad (1)$$

Volume of material = Total Length of cut (Perimeter) × specimen thickness × Wire Dia.
Perimeter = 4×Path of cut (10mm)
Dia. of Wire = 0.25mm
Specimen Thickness = 5mm

Time taken for machining of the specimen during experimentation is recorded using a stopwatch.

Calculate the MRR of all the specimens using the above equation (1)

$$MRR = \frac{4\times10\times0.25\times5}{11} = 4.56\text{mm}^3/\text{min}$$

A measure of how well-machined components perform in practical applications is surface roughness (Ra), which is influenced by the type of contact, precision, and shape of the components. Understanding how cutting input parameters impacts the roughness of the specimen's machined regions is also essential. MRR and Ra of all experiments are tabulated in Table 5.

Table 5. Input parameter vs output

S.No	T_{on} (μ-s)	SV (V)	WT (N)	MRR (mm^3/min)	Ra (μ-m)
1	80	50	12	4.56	3.05
2	95	80	11	4.11	3.25
3	95	65	11	4.22	3.35
4	110	80	10	4.55	3.45
5	95	65	10	4.50	3.55
6	95	65	11	4.66	3.40
7	95	65	11	4.57	3.30
8	110	50	10	5.10	3.66
9	80	50	10	4.26	3.45
10	80	65	11	4.30	3.27
11	110	65	11	4.81	3.59
12	95	65	12	5.00	3.15
13	95	65	11	4.60	3.37
14	95	65	11	4.69	3.42
15	80	80	12	4.33	2.98
16	80	80	10	3.75	3.09
17	95	65	11	4.90	3.21
18	110	80	12	4.64	3.41
19	95	50	11	4.95	3.28
20	110	50	12	5.25	3.56

3. Results & Discussion

3.1 Mathematical modeling:

Relation of output as a function of input parameter is given in equation (2)

$$Y = f(Ton, SV, WT) \tag{2}$$

Where Y represents the responses and T_{on} – Time of Pulse-on, SV- Servo-Voltage, and WT- Wire-tension. Generally, for four input variables a second-degree polynomial equation is developed to be represented by equation (3)

$$Y_u = \beta_0 + \sum_{i=1}^{4} \beta_i X_{iu} + \sum_{i=1}^{4} \beta_{ii} X_{iu}^2 + \sum_{i=1}^{4} \beta_{ij} X_{iu} X_{ju} \tag{3}$$

X_{iu} is the input standards of the i_{th} machining inputs for the experiment, n is the number of inputs, β_0 represents the constant term, β_i represents a linear parameter, β_{ii} represents the coefficient of quadratic parameter, β_{ij} represents the interaction coefficient, Yu represents responses, e.g., Material removal rate (MRR) and Surface Roughness (SR)[20].

3.2 Analysis of Variance (ANOVA)

When determining the parameter importance to allocate the discrepancy in components to control variables and error, analysis of responses (ANOVA) is a crucial technique. At a 95% confidence level, ANOVA was conducted. Considering a certain output measure, the parameters that had P-values less than 0.05 were determined to be significant[21]. The measured response variables and controllable parameter data are fed into the Minitab statistical analysis program. The results are assessed and analyzed using the software's design of the experiment (DOE) module[22]. An increase in F values results in a change in the presentation of process parameters[23]. ANOVA outcomes of MRR are represented in Table 6, which depicts that pulse on duration and Servo voltage have a good effect on material removal rate as their F values are greater and P values are smaller among all. R^2 and modified R^2 values are 95.29 % and 91.05 % indicating models are in fit with the data, Pulse on has the most effect on MRR as the F value is 17.51 the highest, the P value is 0.002 ≤0.05, followed by servo voltage whose F value is 12.51 second highest and the P value is 0.005≤0.05 which as revealed in Table 6. Pulse on has about 33.846 % contribution to the Material removal rate (MRR) and Servo voltage has about 24.183 % contribution[24].

Table 6. ANOVA for MRR for input parameters

Sour.	DF-	AD SS	AD MS.	F	P	%C
(T_{on})	1	0.70225	0.702250	17.51	0.002	33.846
(SV)	1	0.50176	0.501760	12.51	0.005	24.183
(WT)	1	0.12544	0.125440	3.13	0.107	6.045
Ton^2	1	0.02676	0.026755	0.67	0.433	-
SV^2	1	0.04204	0.042036	1.05	0.330	--
WT^2	1	0.02554	0.025536	0.64	0.443	
Ton*SV	1	0.00080	0.000800	0.02	0.890	
Ton*WT	1	0.16245	0.162450	4.05	0.072	
SV*WT	1	0.06480	0.064800	1.62	0.232	
Err	10	0.40111	0.040111			
Total	19	2.07478				

The results of ANOVA for Surface roughness (SR) for various input parameters are depicted in Table 7, Which suggests that pulse on and wire tension have more effect as their F values are higher and P values are less. R^2 = 87.67 % and modified R^2 =76.57% show that the model is in fit. Pulse-on has the highest F values of 42.82 and P value of 0.00 ≤0.05 which has a high influence, followed by Wire Tension whose F value is 11.04 and P value is 0.008 ≤0.05 as represented in Table 7[25]. Pulse on Time has got contribution of about 52.82% and Wire Tension has about 13.618 % contribution.

Table 7. ANOVA results for Ra estimated Regression

Sour.	DF	AD SS	AD MS	F	P	% C
Ton	1	0.364810	0.364810	42.82	0.000	52.820
SV	1	0.081000	0.081000	9.51	0.012	11.723
WT	1	0.094090	0.094090	11.04	0.008	13.618
Ton2	1	0.014911	0.014911	1.75	0.215	-
SV2	1	0.022955	0.022955	2.69	0.132	-
WT2	1	0.000111	0.000111	0.01	0.911	-
Ton*SV	1	0.002813	0.002813	0.33	0.578	-
Ton*WT	1	0.010513	0.010513	1.23	0.293	-
SV*WT	1	0.023113	0.023113	2.71	0.131	-
Err	10	0.085196	0.008520			-
Total	19	0.690895				

The involvement of inputs in outputs using the Anova table has been plotted. Figure 3 represents the contribution plots.

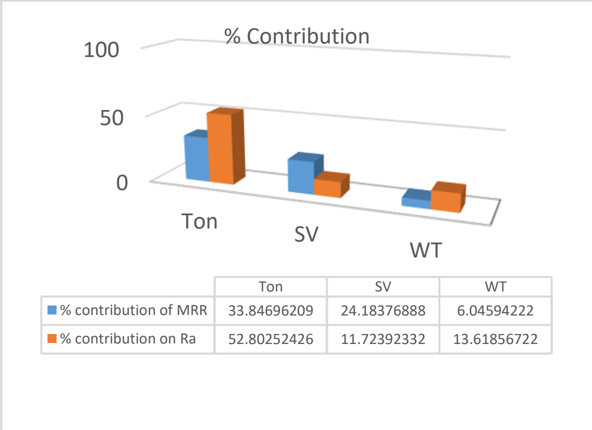


Fig. 3: % Contri. of Responses

3.3 Regression Model of Output Responses

The performance of the WEDM process on Nimonic 90 with brass electrode is predicted by using an empirical model consisting of equations to give a relation of output responses with the independent set variables such as Pulse on, Servo voltage, and wire tension. The effects of inputs on outputs are shown in Equation (4) and Equation (5). Equation (4) represents the dependence of MRR with input parameters, which shows that Pulse-on has a positive impact and servo voltage, and wire tension has a negative impression on it. Also, Equation (5) represents the effect of independent variables like pulse on time, servo voltage, and wire tension, along with the combined effect of inputs on Surface roughness. Pulse on time, Servo voltage, and wire tension have a negative influence on Surface roughness.

$$MRR= 2.7+ 0.203\ Ton- 0.0137\ SV- 1.50\ WT - 0.000438\ Ton^2- 0.000549\ SV^2+ 0.096\ WT^2+ 0.000044\ Ton*SV- 0.00950\ Ton*WT + 0.00600\ SV*WT \quad (4)$$

$$Ra= 9.66 - 0.0814\ Ton - 0.0005\ SV - 0.42\ WT + 0.000327\ Ton^2- 0.000406\ SV^2- 0.0064\ WT^2 + 0.000083\ Ton*SV+ 0.00242\ Ton*WT + 0.00358\ SV*WT \quad (5)$$

Using Minitab software, the normal probability plots are drawn as shown in Figure 4 (a &b) for Material removal rate (MRR) and Surface roughness (SR). As of the graph, it is clear residue points are close to linear fit and hence the results of the experiment are spread normally.

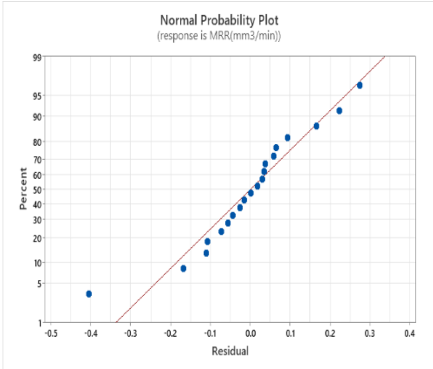


Fig. 4 (a): Plot representing Normal probability of MRR

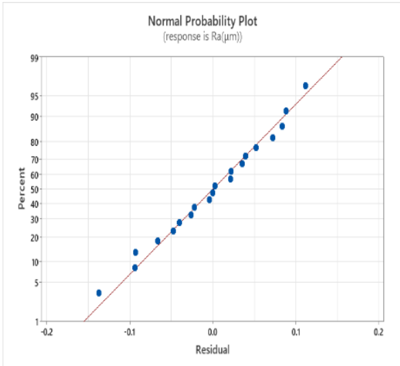


Fig. 4 (b): Plot representing Normal probability of Ra

A Pareto chart of Material Removal Rate (MRR) and Surface Roughness (SR) are shown in Figure 5 (a &b), which are used to find the most prompting parameters graphically. In Pareto charts, the factors whose values are beyond the red mark are influential parameters. In Figure 5(a) the Pareto chart of MRR depicts that Pulse on Time and Servo Voltage are the most prompting parameters as their values are beyond 2.228. From Figure 5 (b), the Pareto chart of Ra shows that Pulse on, Servo voltage, and Wire Tension are influencing constraints as their values in the Pareto chart are beyond 2.228[26].

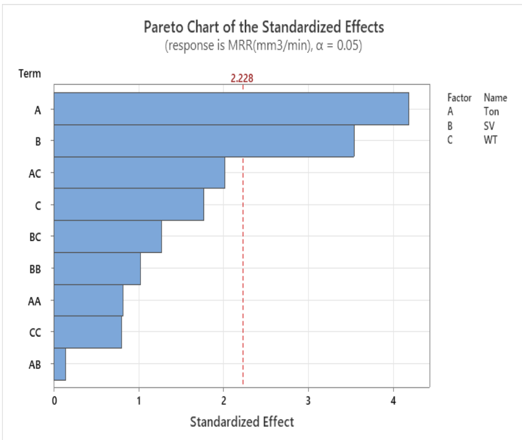


Fig. 5 (a): Pareto Chart of Material Removal Rate

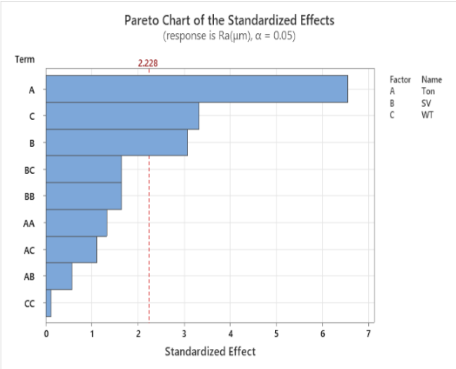
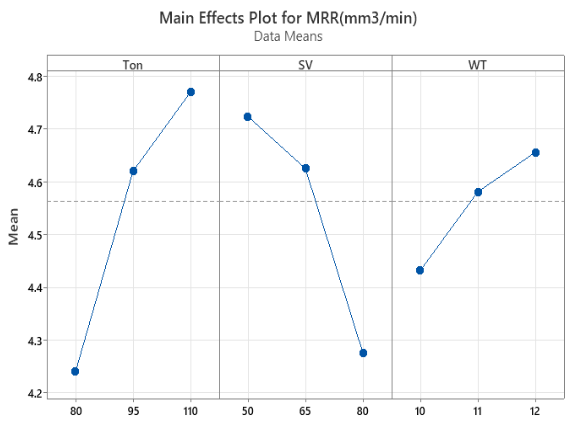


Fig. 5 (b): Pareto chart of Surface Roughness

3.4 Effects on Inputs on Output

3.4.1 Impact of Inputs on MRR

The effect of input parameters on the material removal rate (MRR) is shown in Figure 6 (a, b &c), which are plotted based on WEDM machining Nimonic 90 using brass wire. Figure 6 (a, b & c) displays the variation of material removal rate with Pulse on, Servo voltage, and wire tension, which shows material removal rate increases with an increase in pulse on time, Wire tension, and material removal rate decreases with an increase in Servo voltage. An upsurge in Pulse on time leads to a rise in the material removal rate, this is due to growth in energy discharged to the surface of the workpiece. That causes the melting and vaporizing of particles from the surface in large amounts. Thus, more material is removed with growth in Pulse on time[27]. As pulse on time rises from 80 to 95 µs, it is observed that there is a sharp growth in Material removal rate i.e., from 3.75 to 4.55mm^3/min this is due to the fact more amount of energy is discharged in a short period hence material removal rate increases faster, whereas if pulse on time is increased further will lead to increase in discharge of energy but material removal rate increases slowly from 4.55mm^3/min to 5.25 mm^3/min. This is because if pulse time is increased from 95 to 110 µs leads to a decrease in the coefficient of chip reduction that improves the rate of plastic deformation. This leads to a high Material removal rate (MRR)[28]. Figure 6 (b) represents the effect of Servo voltage on the Material removal rate (MRR). As Servo voltage increases even though there is an increase in current it is not able to transfer heat between the electrodes, because of more gaps developed between the electrodes. Thus, with a surge in Servo voltage, less energy is transferred between the electrodes leading to a decline in the material removal rate from the surface[29]. As the Servo voltage changes from 50 to 60 V the spark intensity will be less as the gap widens amongst the electrodes which results in a lower material rate. Further increase in Servo voltage from 65 to 80V increases the gap amid the electrodes and leads to a drop in spark intensity hence material removal rate decreases at a faster rate. Hence material removal rate shrinks with an increase in servo voltage[30]. Figure 6 (c) displays the variation of material removal rate (MRR) with Wire Tension. It is observed that with the rise in Wire-tension, there is an upsurge in MRR. Throughout the sparking process, the wire travels at a constant rate. The moving wire is subjected to an impact force from the spark, and it is expected that the wire will vibrate. Variations in wire tension are anticipated to increase the rate of wire vibrations on each influence. This force of impact exerted by the wire is relatively little, but the frequency of the impact is extremely high since the rate of sparking is more, which creates very less vibrations. As Wire tension increases from 10 to 12 N, there is a decrease in vibrations in the wire. An increase in WT will reduce vibrations, and deflections in wire and improve the stable distribution of energy among the wire electrodes and workpiece increasing the efficiency of machining, thus MRR increases[31]

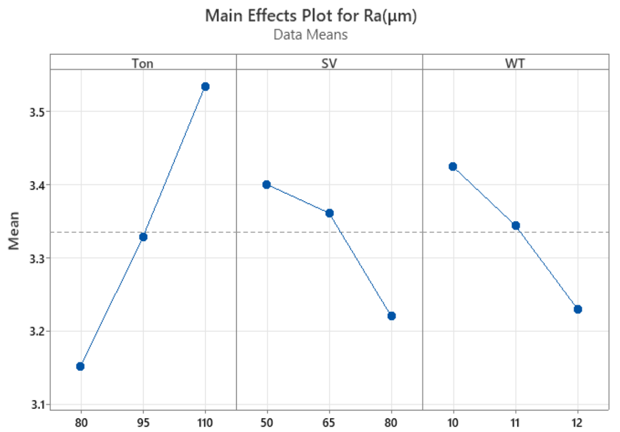


6 (a) 6 (b) 6 (c)

Fig. 6 (a, b &c): Variation of MRR with Inputs

3.4.2 Influence of Inputs on Ra

The effect of input parameters on surface roughness is shown in Figure 7(a, b & c) plotted for the results obtained after WEDM machining of Nimonic 90 using brass wire. Figure 7 (a, b & c) shows the variation in surface roughness to pulse on, Servo voltage, and wire tension. Surface roughness surges with a rise in Pulse on and declines with an increase in servo voltage and wire tension. In Figure 7(a) it is detected that as Pulse on growths, there is a rise in Surface roughness linearly. As Pulse-on time increases there is an increase in discharge energy, which produces a larger crater on the surface and causes more surface roughness. Pulse on time affects more on surface roughness of the material [32]. As the Pulse-on duration changes from 80 to 115µs, the amount of heat energy increases. This high thermal energy reaches the workpieces and creates an impact on the Surface that causes fast evaporation of material and develops large, deep, craters which leads to a rise in surface roughness values from 3.05 to 3.66 µm[33]. Figure 7 (b) shows that as Servo voltage increases there is a reduction in surface roughness slowly during the initial stage i.e., from 50 to 65V, thereby it decreases linearly from 65 to 80V. When Servo voltage increases from 50 to 65V it is observed that there is a decrease in 3.66 to 3.55 µm which creates stable spark intensity and energy is dispersed uniformly which leads to a reduction in surface roughness[34]. When voltage is increased further from 65 to 80V the discharged energy reduces as energy absorbed by the dielectric medium reduces due to an increase in the gap between the electrodes. This low-energy transfer creates smaller craters from the surface of the workpiece and provides a better surface[35]. Figure 7 (c) shows that surface roughness follows a reverse trend to wire tension. When Wire tension increases it is observed that surface roughness falls linearly to 2.98 µm. As Wire tension leads from 10 to 12N this creates high tension in the wire electrode between the guide ways. This high tension reduces bend of the wire that is developed due to unbalanced force acting on the wire i.e., Pressure of dielectric fluid and reaction force induced by the sparks. Undeflected wire cuts the workpiece in straight path which makes a better cutting quality on the specimen. Thus, roughness reductions with increase in wire tension[36].



7 (a) 7 (b) 7 (c)

Fig. 7(a, b & c): Variation of Surface Roughness with Inputs

3.5 Analysis of Surface Characteristics

Analysis of surface characteristics is done by using SEM to study the variations that happened on the surface due to which properties of the surface will be varied. It is detected that on the surface there is the creation of a recast layer, Globules, Debris, microcracks, and black spots. SEM images were taken for the specimens with High and Low MRR shown in Figure 8 and Figure 9, and also for Specimens with High and Low surface roughness which are shown in Figure 10 and Figure 11. Figure 8 which was taken for the highest Material removal rate has more Globules, recast layer, Black Spots, and Microcracks on the surface of the specimen which was observed at 50µm. Figure 9 shows an SEM image of a specimen with the lowest Material removal rate in which the recast layer, small globules, and microcracks are observed at 100 µm. Figure 10 shows an SEM image of a specimen whose Surface roughness is high with Globules, Debris, Black spots, and microcracks. Figure 11 shows an SEM image of a specimen with low Surface roughness. Globules are melted metals that get deposited on the surface as they cannot evaporate completely from the surface, and are re-condensed[37]. When the molten material wasn't thoroughly flushed by the dielectric fluid, debris developed. When the material's fracture strength is exceeded, high thermal stress that develops as a result of rapid cooling or uneven cooling causes the crack to form. Electric spark-melted material that resolidifies on the surface without being ejected or flushed away forms a recast layer. An increase in servo voltage initially will lead to increases in surface roughness as there is more thermal energy developed between the electrodes that causes the material to form a molten pool that gets condensed on the surface thus Globules are formed on the surface[38]. When pulse-on time increases, a large volume of energy in the form of heat gets diffused to the work specimen that melts and evaporates more material, but during dielectric cooling and flushing molten metal becomes re-solidified on the surface. This creates a recast

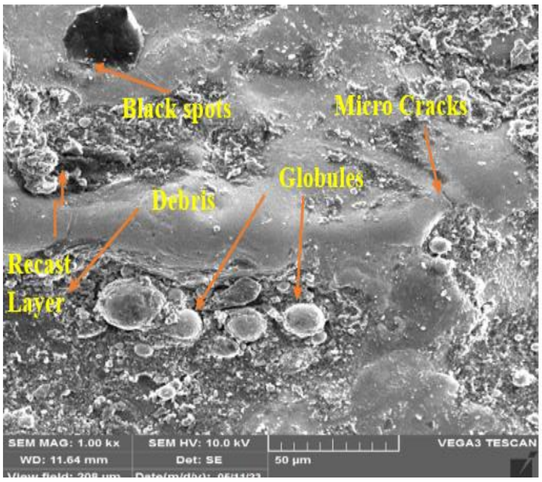


Fig. 8: SEM of the machined sample with high MRR

layer, debris, and microcracks which worsens the surface[39]. Wire tension has less consequence on surface characteristics, when wire tension is enlarged there is an even sparking in energy between the electrodes that causes less formation of debris and craters[40]

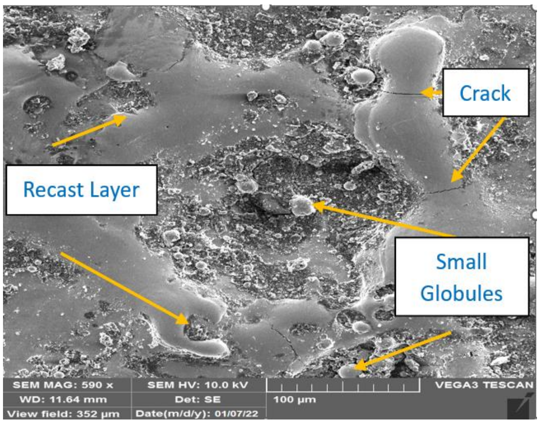


Fig. 9: SEM of a machined sample with Low MRR

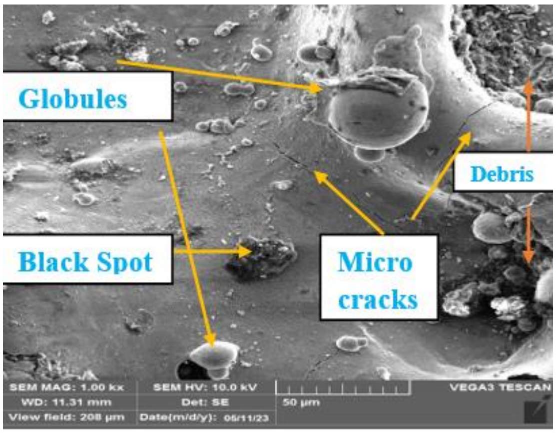


Fig. 10: SEM of a machined sample with High Ra

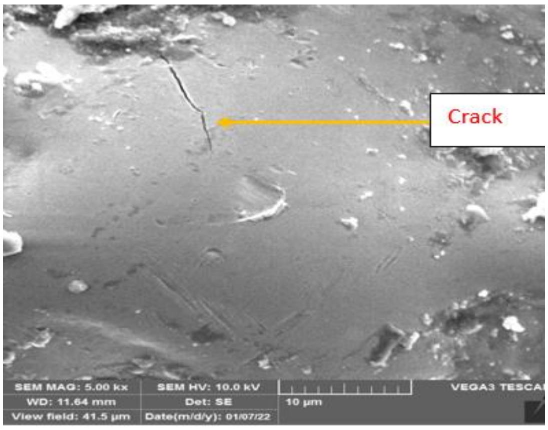


Fig. 11: SEM of a machined sample with Low Ra

4. Conclusion

Nimonic 90 machined using WEDM taking brass as wire electrode. RSM designed the tests for this study using three levels of Pulse-on Time, Servo Voltage, and Wire-Tension as input parameters. To comprehend the impact of inputs on outcomes (MRR & Ra), main plots are created using Minitab.

- Pulse-on time and wire-tension have a greater impact on material removal rate than servo voltage, but on surface quality Wire-tension and Servo voltage have better influence than Pulse-on time.
- MRR records less with development in servo voltage but surges with wire tension and pulse on time. Surface Quality declines with the rise in pulse-on time and grows with the rise in wire-tension and servo voltage.
- The highest material removal rate that is 5.25mm^3/min is obtained when the Pulse on time (110 µs) and wire tension (12N) is high and servo voltage is low (50V).
- The lowest surface roughness is 2.98 µm which is obtained when pulse on time is low (80 µs) and servo voltage (80V), wire tension is high (12N)
- Pulse on time has highest contribution for both material removal rate and surface roughness followed by servo voltage and Wire tension for material removal rate, where as for surface roughness wire tension and servo voltage followed to pulse on time.
- Rate of material removed and roughness in Surface i.e., output responses are modelled using Minitab software. Normal plots and Pareto charts are also obtained from Minitab. Normal plots infer that experimental results are in agreement with theoretical values whereas Pareto charts help to identify which parameters have more influence on output responses.
- SEM images which are taken for Low surface roughness and High surface roughness. Formation of globules, Debris, Mirco cracks, craters, and recast layers are formed.

Future Scope

- Machining of Nimonic alloys using cryogenics liquids has to be studied
- Study of EDX of the wire electrode and surface of the sample has to be studied

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