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Optimization of machining parameters in machining nimonic C-263 by WEDM process

This paper discusses an experimental work carried out to optimize the machining parameters in machining Nimonic C263 by WEDM. Nimonic 263 is used as the workpiece material. Machining is performed with CNC wire cut electric discharge machine. Deionized water is used as dielectric fluid and molybdenum wire of diameter 0.18mm is used as the wire electrode material. Input parameters considered in this project work are pulse ON time (tonne), pulse OFF time (Toff), peak current (Ip) and voltage (V). Cycle time is considered as the output parameter. Robust design study is carried out to perform design of experiments from identifying the main factors, their levels and noise factors to predict the performance under these levels. 27 machined pieces are performed based on different set of levels for different factors. DK 7735 machine is used to perform machining process. After calculating the time, results are fed into the MINITAB 17 software to obtain optimized combination of levels of different factors from Taguchi's analysis and signal to noise ratio response table. ANOVA table is used to calculate the influence of each input parameters on output results. To validate the simulation, the predicted results are compared to experimental results. Optimum combinations of levels are substituted in the mathematical equation in order to obtain the predicted result.

Keywords*:* Nimonic C-263, WEDM, MINITAB, ANOVA, SN ratios

1.0 Introduction

Recent development in technology and application of harder materials in manufacturing field leads to development of highly efficient machines, which can be used to cut harder materials and can be utilized in machining intricate shapes with higher surface finish. Requirement of material with high resistance to wear, high temperature resistance, high strength in aircraft industries and manufacturing field results in development of non-conventional process in machining. In non-conventional machining process - energy is directly applied to the surface of the material to be machined, regardless of metal cutting.

The Erosive effect of EDM was first detected by Priestley, the english scientist during 1970. Lazarnko the Soviet scientist, after research he decided to utilize the destructive effect of electric discharge to develop the method of metal machining. The electric discharge machining is a thermal metal cutting process which is used to machine complicated shapes and very hard material having high temperature resistance. As compared to conventional machining process this machine uses tool electrodes having feed movement with precision control. Metal is removed by electric spark for a very short duration of time. Hard material such as tungsten carbide, Inconel, hard steel etc. can also be machined with this non-conventional machining process.

In EDM dielectric fluid which is provided between workpiece and tool electrode is initially non-conductive. For the production of discharge, the necessary condition is to ionize the dielectric fluid (i.e. breaking of its molecule into ions and electrons), so that current starts flowing from anode to cathode. Transfer of heat from spark to workpiece and tool, partially vaporizes and melts the metal in a thin surface layer. Wire EDM, the most diversified machine tool, was introduced in the late 1960's. Wire electric discharge machining is a boon for mold, tool and die steel and metal working industries. Wire EDM can machine many types of material no matter how hard the material is, but the material should be electrically conductive. It can machine common materials such as aluminum, tool steel, copper and also alloy materials like Inconel, carbide and hastelloy etc. Wire EDM produces workpieces with high surface finish and tool wire never comes in contact with workpiece, so produces burr free finished product. As there is no contact made between the workpiece and tool, the workpiece is free from any damage by cutting force like in conventional machining.

Wire electric discharge machine uses single stir and metal wire as a tool electrode in order to carry out the machining process. Presently coated wires are used in place of brass wire for better efficiency. The wire is held between the upper and lower guide, so that it can cut the metal by one side to another. Movement of wire is controlled by CNC, so feeding of required dimension and path of cut has to be done

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manually. Upper wire guide can move in the X axis- Y axis- Z axis in all three-directions, this gives the wire the ability to cut taper and transition shape. When current is applied to the electrode, thousands of sparks are generated between the tool and workpiece in 1/100000th second. This actually leads to an increase in temperature and energy results in melting of workpiece material. WEDM generally uses deionized water as dielectric fluid which carries away the unwanted debris from the spark gap. Removal of material takes place during ON time of sparks, not due to the flow of current.

2.0 Experimentation

To carry out the machining process, a DK 7735 wire electric discharge machine is used. This machine consists of an electrode wire feed mechanism, servo control, dielectric fluid supply system, work table and a digital console for controlling the operation. Deionizer water is used as dielectric fluid in this machine.

Fig.1: DK 7735 wire electric discharge machine

Monitor is provided in the console to set the desired parametric values for each different experiment. Alignment of the specimen with respect to cutting wire is done in such a way that it will cut the material from mid-point in a longitudinal direction.

During the cutting process, the path of the cut can be checked by the operator through the monitor. Once it is completed the path, machining has to be stopped through stop command. Workpiece material is clamped to a magnet holder in order to place it for machining.

Test specimen: Nimonic C-263

Nimonic C-263 superalloy, which is extensively used in aerospace industries for the turbine blade manufacturing, was selected as target material for the experimental studies. The procurement of material was in a circular rod shape of diameter 22mm and length 150mm. The mechanical and physical properties of Nimonic C-263 are given in Table 1.

- Surface-roughness
  In single pass at 60 sq mm/min: <2.5 Ra
  In multi pass at 60 sq mm/min:< 1.8 to1.2 Ra
- Machine accuracy
  In square : 0.01mm
  In circle : 0.02mm
  In tapper : 0.05mm
- Pitch accuracy
  In longitudinal : 0.02mm for 250mm
  In transverse : 0.02mm for 200mm
- Machine noise : 80dB

Input parameters with range

Input parameters like peak current, pulse on time, pulse off time and voltage are considered for machining purpose with range. Using these variable parameters, machining is carried out at different levels. Total 27 experiments are carried out at different levels of factors according to the standard orthogonal array.

Table 1: Physical and mechanical property of nimonic C-263

1.	Physical property density	Metric 8.36g/cm^3
2.	Mechanical property tensile strength	Metric 940MPa

Table 2: Chemical composition of nimonic-263

	Element	Raw material – % of composition
1.	Nickel (Ni)	51.351
2.	Carbon(C)	0.064
3.	Silicon (Si)	0.02
4.	Manganese (Mn)	0.34
5.	Sulphate (S)	0.005
6.	Chromium (Cr)	20.48
7.	Iron (Fe)	0.32
8.	Molybdenum (Mo)	5.70
9.	Cobolt (Co)	19.19
10.	Copper (Cu)	0.01
11.	Titanium (Ti)	2.01
12.	Aluminium (Al)	0.51

Table 3: Input parameters with range

Machining parameters	Range
peak current (A)	3-5
on-time (μs)	30-50
off-time (μs)	8-12
Voltage (V)	80-100

Fig.2: Nimonic C-263 machined by WEDM

Machined Nimonic C-263 alloy was having a diameter of 22mm and thickness of 2mm. totally 27 pieces are machined for the present study. Fig.2 shows the Nimonic C-263 machined by WEDM.

After machining, the surface-roughness of the machined surface is measured using Surftest SJ-210 surface-roughness tester. The roughness tester used for this work is a contact type tester. It has a stylus to make contact with the workpiece. For each workpiece, the roughness is measured at three different locations on the machined surface and the average is taken. The sampling length is to be fed manually into the roughness tester. Sufficient care should be taken, that roughness range of the specimen should not be beyond the limits of the measuring instrument, to avoid the damage of the stylus of the instrument. The roughness parameter considered for this work is roughness average, R_a.

3.0 Results and discussion

Nimonic C-263 is machined by wire electric discharge machine using molybdenum wire of diameter 0.18mm. Machining is carried out at different factor level combinations. All

Table 4: Results of orthogonal array for L27 Taguchi design

	Voltage (Volt)	Pulse ON (microsecond)	Pulse OFF (microsecond)	Current (ampere)	Cycle time (min)	MRR mm^3/min	Ra (μm)
1	80	30	8	3	10.26	7.41	2.21
2	90	30	10	3	10.22	7.44	2.46
3	100	30	12	3	12.2	6.23	2.96
4	90	40	8	3	10.12	7.51	2.73
5	100	40	10	3	11.4	6.67	2.62
6	80	40	12	3	12.32	6.17	2.43
7	100	50	8	3	9.5	8.00	2.75
8	80	50	10	3	11.3	6.72	2.68
9	90	50	12	3	12.3	6.18	2.46
10	80	30	8	4	6.14	12.38	2.95
11	90	30	10	4	7.36	10.32	2.83
12	100	30	12	4	9.06	8.49	2.74
13	90	40	8	4	7.27	10.45	2.79
14	100	40	10	4	7.58	10.02	2.63
15	80	40	12	4	8.42	9.02	2.57
16	100	50	8	4	7.14	10.64	2.84
17	80	50	10	4	7.47	10.17	2.69
18	90	50	12	4	8.48	8.96	2.75
19	80	30	8	5	7.18	10.58	2.84
20	90	30	10	5	8.19	9.28	2.65
21	100	30	12	5	8.53	8.91	2.46
22	90	40	8	5	7.37	10.31	2.73
23	100	40	10	5	8.19	9.28	2.66
24	80	40	12	5	9.14	8.31	2.47
25	100	50	8	5	7.23	10.51	2.82
26	80	50	10	5	8.24	9.22	2.61
27	90	50	12	5	9.33	8.14	2.44

Fig.3: Surface-roughness testing machine

machining data is tabulated in a standard orthogonal array table, through which analysis is carried out to obtain the effect of factors on the output parameter. Our concern is to obtain material removal rate during the machining process and to get the optimized combination of levels of factors in order to get optimum surface-roughness. ANOVA technique is used to obtain the percentage contribution of factors on response value. Signal-to-noise ratio is calculated in order to get mean effect plot for smaller the better result in the material removal rate and surface-roughness. Here surface-roughness and material removal rate are the output parameters.

Formula used

Material removal rate

MRR= $\pi * r^2 * h/t$ (mm^3/min)

where, r = radius of the specimen, mm

h = diameter of the wire, mm

t = time taken for cutting, min

Evaluation of contribution of factors on response value through ANOVA (Fig.4 and Table 6)

Table 7 shows the number of factors and number of levels contained in each factor. In this experiment we have three levels for all factors.

Table 5: Response table for signal to noise ratios for MRR

Level	Peak current	On- time	Off- time	Voltage
1	–16.77	–18.91	–19.66	–18.78
2	–19.98	–18.59	–18.77	–18.70
3	–19.42	–18.68	–17.75	–18.69
Delta	3.21	0.32	1.91	0.09
Rank	1	3	2	4

Table 6: Response table for signal to noise ratios for Ra

Level	Peak current	On-time	Off-time	Voltage
1	–8.234	–8.519	–8.73	–8.29
2	–8.794	–8.376	–8.453	–8.448
3	–8.39	–8.522	–8.235	–8.68
Delta	0.56	0.146	0.494	0.39
Rank	1	4	2	3

Table 7: Tabulation of factors and levels

Factor	Type	Levels	Values
Voltage	Fixed	3	80,90,100
Pulse ON	Fixed	3	30,40,50
Pulse OFF	Fixed	3	8,10,12
Current	Fixed	3	3,4,5

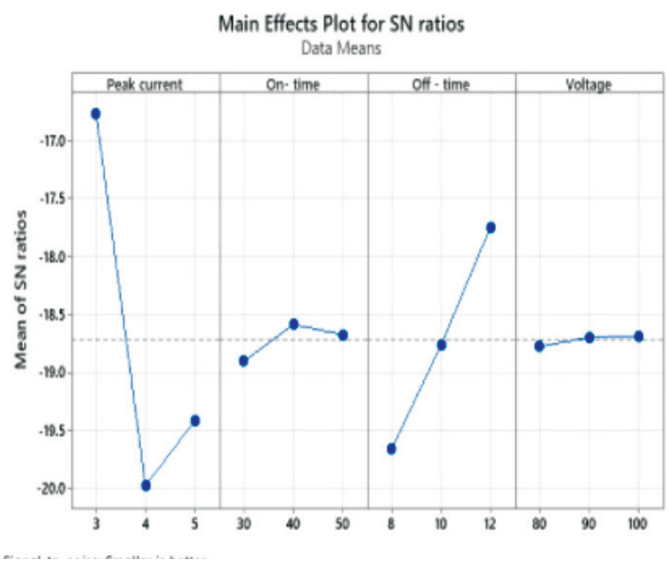

Fig.4: Taguchi analysis on MRR

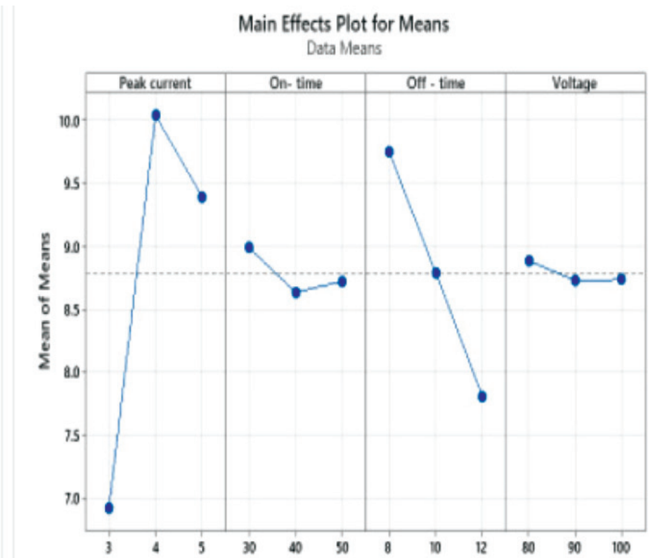

Fig.5: Taguchi analysis on Ra.

Table 8: Tabulation of analysis of variance for SN-ratios of MRR

Source	DF	Sum of squares	Mean of square	F-value	P-value
Peak current	2	52.9062	52.9062	26.4531	137.91
On- time	2	0.48	0.48	0.24	1.25
Off – time	2	16.4407	16.4407	8.2203	42.86
Voltage	2	0.043	0.043	0.0215	0.11
Residual error	6	1.1509	1.1509	0.1918	
Total	26	72.3041			

Table 9: Tabulation of analysis of variance for SN-ratios of Ra

Source	DF	Sum of squares	Mean of Square	F-Value	P-Value
Peak current	2	1.5048	1.5048	0.7524	1.93
On- time	2	0.1252	0.1252	0.06258	0.16
Off – time	2	1.1054	1.1054	0.55272	1.41
Voltage	2	0.6943	0.6943	0.34717	0.89
Residual error	6	2.3447	2.3447	0.39078	
Total	26	9.0793			

Table 10: Optimized Values of MRR

Parameters	Voltage (V)	Pulse ON (µs)	Pulse OFF (µs)	Peak current (ampere)
Optimized values	80	30	8	4

Table 11: Optimized values of Ra

Parameters	Voltage (V)	Pulse ON (µs)	Pulse OFF (µs)	Peak current (ampere)
Optimized values	100	30	12	3

From the ANOVA (Table 8), it can be seen that peak current contributes to a higher degree in material removal rate, whereas voltage has lesser contribution to Material removal rate.

From the ANOVA (Table 9), it can be seen that peak current contributes to a higher degree in surface-roughness followed by pulse off time, whereas pulse on-time has lesser contribution to surface-roughness.

From the response table we can influence the parameters to the most critical level in MRR is peak current. Following that order pulse OFF time and ON time influences them in the next level. The optimized values are,

Also from the response table of surface-roughness, peak current influences the most and then comes pulse OFF and voltage parameters.

4.0 Conclusion

In this investigation on the optimization and the effect of machining parameters on the MRR and the surface finish in WEDM operations. The effect of various machining parameter such as pulse on time & pulse off time has been studied through the machining of Nimonic C-263. The level of importance of the machining parameters on the MRR and the surface finish was determined by using Response table method, the highly effective parameters on both the MRR and the surface finish were found, as peak current, Pulse OFF-time more than the other parameters. An optimum parameter combination for the maximum MRR and minimum surface-roughness was obtained by using the analysis. The confirmation tests indicated that it is possible to increase MRR and decrease surface-roughness significantly by using the proposed statistical technique. The experimental results confirmed the validity of the used Taguchi method for enhancing the machining performance and optimizing the machining parameters in WEDM operations.

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