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EXPERIMENTAL INVESTIGATION ON EFFECTS OF CUTTING PARAMETERS ON MRR IN WEDM PROCESS

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ABSTRACT
Wire Electrical Discharge Machining (WEDM) is one of the important non- traditional machining processes. The Wire Electrical Discharge Machining plays an important role in manufacturing sectors especially industries like aerospace, automobile and general engineering etc. Intricate profiles used in prosthetics, bio medical applications can also be done in WEDM. INCONEL-825 is a nickel-based high-temperature strength super alloy found applications in aerospace, missile, nuclear power, chemical and petro chemical, heat treatment, marine and space shuttle components. The characteristics such as higher strain hardening tendency, high dynamic shear strength and poor thermal diffusivity are the major causes of difficulty in machining of this alloy. These, in turn produce higher cutting forces, highly strain hardened and toughened chips and cause surface damages extending to subsurface levels. All these effects, in general, hamper the machinability of this alloy.

Keywords:
Inconel-825, EDM, Taguchi, MRR, Traditional Machining.

INTRODUCTION

Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machining(EDM) etc. are applied to machine such difficult to machine materials. Wire Electrical Discharge Machining(WEDM) process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective of their hardness and toughness Furthermore, WEDM is a capable of producing a fine, precise, corrosion and wear resistant surface. WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. WEDM has been found to be an extremely potential electro-thermal process in the field of conductive material machining. WEDM has many applications in aerospace, automotive and medical industries to produce complex and intricate shapes. The most important performance factors in study of WEDM are material removal rate (MRR), surface finish and cutting width (kerfs). They depend on machining parameters such as discharge current, pulse duration, pulse frequency, wire speed, wire tension, type of die electric fluid and dielectric flow rate. Selection of optimum machining parameter combinations for obtaining higher accuracy is a challenging task in WEDM due to the presence of a large number of process variables and complicated stochastic process mechanisms.

Review on WEDM machining:

Tarng et al. [1] formulated a neural network model and simulated annealing algorithm in order to predict and optimize the surface roughness and cutting velocity of the WEDM process in machining of SUS-304 stainless steel materials. Spedding et al. [2] developed mathematical models to predict material removal rate and surface finish while machining D-2 tool steel at different machining conditions. It was found that there is no single combination of levels of the different factors that can be optimal under all circumstances. He attempted to model

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the cutting speed and surface roughness of WEDM process through the response surface methodology and artificial neural networks (ANNs) and have found that the model accuracy of both the approaches were better. Neeraj Sharma et al. [3] studied the effects of various process parameters of WEDM as pulse width, time between two pulses, maximum feed rate, servo reference mean voltage, short pulse time and wire mechanical tension. By machining cryogenic-treated D-3 material, they have been evaluated to maximize surface roughness (sr). l. Experimental observations were based on Taguchi's L-27 orthogonal array; Signal to-Noise (S/N) ratio, Analysis of Variance (ANOVA) and various plots are used to find the optimum process parameter with a least surface roughness. Huang et al. [4] presented the use of Grey relational and S/N ratio analyses, for determining the optimal parameters setting of WEDM process. The data showed that the table feed rate and pulse on time have immediate effects on the MRR and surface roughness.. Nihat Tosan [6] investigated the variation of cutting performance with pulse time, open circuit voltage, wire speed & dielectric fluid pressure in WEDM process by using AISI 4140 steel. The cutting performance outputs considered in the study were surface roughness & cutting speed. He found experimentally that increasing these all cutting parameters increase surface roughness & cutting speed. In addition, the importance of cutting parameters on the cutting performance outputs is determined by using the variance analysis (ANOVA).H. Singh et al. [9] worked on the effects of various process parameters of WEDM like pulse on time (TON), pulse off time (TOFF), gap voltage (SV), peak current (IP), wire feed (WF) and wire tension (WT). They investigated the impact of these parameters on material removal rate of hot die steel (H-11) using one variable at a time approach. Investigations showed that changing the discharge current and pulse time can both enhance surface roughness. Short and long pulses produce the same surface roughness but varied surface morphologies when the pulse energy per discharge is constant.They told that the wire feed and wire tensions are neutral input parameters. The material removal rate (MRR) directly increases with increase in pulse on time (TON) and peak current (IP) while decreases with increases in pulse off time(TOFF) and servo voltage (sv).Vishal Parashar et al. [10] worked on statistical & regression analysis of material removal rate for WEDM of SS304L materials.From the literature, it was observed that a good number of researches have already been done in the area of WEDM technology but for the harder materials not for less harder like SS 316L which has very important application in today's life. To the greatest extent of the authors' knowledge, there isn't a published study that uses Taguchi's parametric design technique and the signal-to-noise (S/N) ratio to optimize the performance characteristics of the WEDM process. (Ramakrishnan and others, [2])Furthermore, one of the most popular machining materials is SS 316L, which is machined using WEDM to create watches and jewelry. Heat exchangers, threaded fasteners, surgical instruments, feed water tubes, water filters, petroleum refining equipment, textile industry equipment, photography industry equipment, and food processing equipment are some of its additional uses. (Spedding and Wang, 1997; Scott et al., 1991). Scott et. al. (1991) developed mathematical models to predict material removal rate and surface finish while machining D-2 tool steel at different machining conditions. It was found that there is no single combination of levels of the different factors that can be optimal under all circumstances. Tarng et. al. (1995) formulated a neural network model and simulated annealing algorithm in order to predict and optimize the surface roughness and cutting velocity of the WEDM process in machining of SUS-304 stainless steel materials. Manna and Bhattacharyya (2004) performed experiments using a typical four-axes Electronica Supercut-734 CNC-wire cut EDM machine on Aluminium-reinforced silicon carbide metal matrix composite Al/SiCMMC. The two key machining parameters for regulating the rate of metal removal are open gap voltage and pulse on period. The cutting speed was greatly impacted by the open gap voltage. The two most important machining factors for surface roughness were wire tension and wire feed rate. The most important factors for regulating spark gap were wire tension and spark gap voltage setting. Miller et al. (2005) looked into how wire EDM micro characteristics were affected by spark cycle and pulse on-time.A variety of materials, including titanium, carbon bipolar plate, and Nd–Fe–B magnetic material, were evaluated for EDM cutting of wires with a minimum thickness of cross section. Ramakrishnan and Karunamoorthy (2005) described the parametric design of Taguchi approach for multi-objective optimization of the WEDM process. In the machining of heat-treated tool steel, the impact of several machining parameters, including wire tension, delay time, wire feed speed, ignition current intensity, and pulse on time, has been investigated. It was identified that the pulse on time and ignition current intensity has influence more than the other parameters Manna and Bhattacharyya (2006) established mathematical models relating to the machining performance criteria like MRR, SR, spark gap and gap current using the Gauss elimination method for effective machining of Al/SiC-MMC. Saha et. al. (2007) developed a second order multi-variable regression model and a feed-forward back-propagation neural network (BPNN) model to correlate the input process parameters, such as pulse on-time, pulse off time, peak current and capacitance with

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the performance measures namely, cutting speed and surface roughness in wire electro- discharge machining (WEDM) of tungsten carbide-cobalt (WC-Co) composite material. 4-11-2 neural network architecture provides the best prediction capability with 3.29% overall mean prediction error, while 6.02% error was revealed by regression model.

WEDM process

WEDM is a process which erodes and removes material by using the channel of plasma generated by electric sparks between two conductive materials (i.e. electrode and the work piece), this channel of plasma converted in to thermal energy at a temperature range of 8000 to 12000℃ at a pulsating direct current supply of 20000 to 30000 Hz. The electrode and work piece are separated by a small gap being immersed in dielectric fluid, an electric spark is produced between this small gap and the work piece material is eroded, as the pulsating current is turned off, the plasma breaks down which leads to sudden reduction in the temperature and the eroded material is flushed away with the help of dielectric fluid in the form of microscopic debris. With each electric spark discharge a small crater is formed on both the work piece and the electrode which is a prime decider in the final surface quality. The taper can ranging from 15^0 for a 100 mm thick to 30^0 for a 400 mm thick work piece can be obtained on the cut surface material.

Table 1: Technical Specifications of Machine Tool

MACHINE TOOL	Ultra Cut CNC F2 WEDM Machine
Design	Fixed table, moving column machine
Table size (mm^2)	860×580
Max. work piece height (mm)	300
Max. Work piece weight (kg)	1000
Main table traverse (X,Y) (mm)	600,400
Positioning Accuracy (mm)	0.005
Positioning Repeatability(mm)	±0.002
Aux. table traverse (u,v) (mm)	80,80
Max. Taper Angle	$\pm 30^0$/50 mm
Max. JOG speed (mm/min)	900
Resolution (mm)	0.0005

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Fig:1 WEDM

OPTIMIZATION METHODS

The objective of the robust design is to find the controllable process parameter settings for which noise or variation has a minimal effect on the products functional characteristics. It is to be noted that the aim is noted that the aim is not to find the parameter settings for the un controllable noise variables, but the controllable design variables. To attain this objective, the control parameters, also known as inner array variables, are mathematically varied as stipulated by the inner orthogonal array. For each experiment of the inner array, a series of new experiments are conducted by varying the level settings of the uncontrollable noise variables. The level combinations of noise variables are done using the outer orthogonal array. The influence of noise on the performance characteristics can be found using the S/N ratio. Where S is the standard deviation of the performance parameters for each inner array experiment and N is the total number of experiment in the outer orthogonal array. This ratio indicates the functional variation due to noise.

Table 2. Experimental data and results for the response parameter, Material Removal Rate (MRR)

S.NO	Servo voltage(SV)	Servo Feed(SF)	Cutting Speed(CS)	MRR	S/N Ratio
1	20	2100	40	1.56	3.862492
2	20	2100	60	1.66	4.402162
3	20	2100	80	1.82	5.201428
4	20	2120	40	1.65	4.349679
5	20	2120	60	1.82	5.201428
6	20	2120	80	1.88	5.483157
7	20	2140	40	1.74	4.810985
8	20	2140	60	1.85	5.343435
9	20	2140	80	1.96	5.845121
10	24	2100	40	1.79	5.057061
11	24	2100	60	1.83	5.249022
12	24	2100	80	1.95	5.800692
13	24	2120	40	1.81	5.153571
14	24	2120	60	1.87	5.436832
15	24	2120	80	1.92	5.666025
16	24	2140	40	1.72	4.710569
17	24	2140	60	1.79	5.057061
18	24	2140	80	1.85	5.343435

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19	28	2100	40	1.35	2.606675

Table 3. Design Experiment

S.NO	Servo voltage	Servo feed	Cutting speed	MRR	S/N ratio
20	28	2100	60	1.41	2.984382
21	28	2100	80	1.44	3.16725
22	28	2120	40	1.42	3.04767
23	28	2120	60	1.53	3.693829
24	28	2120	80	1.57	3.917993
25	28	2140	40	1.56	3.862492
26	28	2140	60	1.66	4.402162
27	28	2140	80	1.71	4.659922

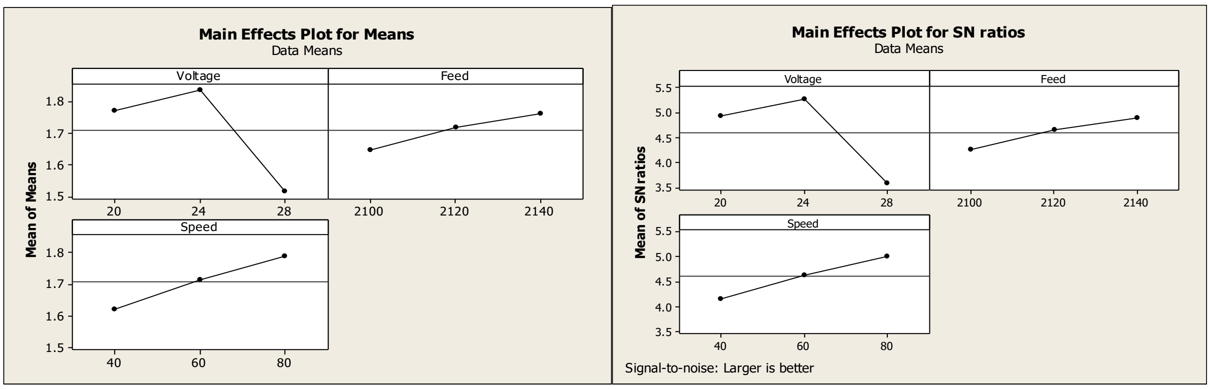

Fig:2 S/N ratio for Metal Removal Rate (MRR) On WEDM

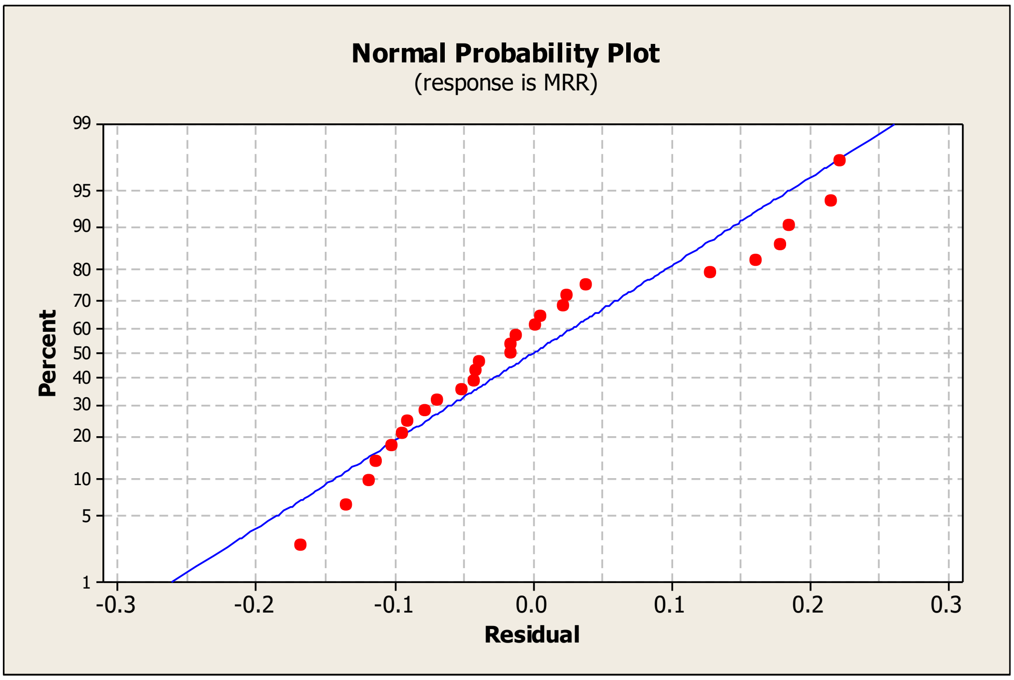

Fig:3 Experimental vs predicted values for MRR in ANOVA

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Table 4 : ANOVA for INCONEL-825 on WEDM for the response MRR

SOURCE	DOF	SUM OF SQUARES	MEAN OF SQUARES	F TEST	% OF CONTIBUTION
Voltage	1	-0.031806	0.007027	-4.53	0.000
Servo Feed	1	0.002861	0.001405	2.04	0.053
Cutting speed	1	0.004167	0.001405	2.96	0.007
ERROR	23	0.32713	0.01422		
Total	26	0.80241			100

From table the % of contribution of values for servo voltage(0.000), servo feed (0.053)and cutting speed(0.007) . It is observed that speed has great influence on Metal Removal Rate(MRR). The results obtained in this study lead to conclusions for machining of INCONEL-825 After conducting the experiments and analyzing the resulting data.

CONCLUSION

. From the results obtained by experiment, the influence on the response parameter Metal Removal Rate (MRR) by cutting parameters like servo voltage, servo feed and cutting speed of cut is :

1. The speed of cut has the variable effect on the Metal removal rate , servo voltage and servo feed an approximate decreasing trend.
2. The design of experiments (DOE), Taguchi method is applied for optimization of cutting parameters and analysis of variance (ANOVA) is done and found that
   a: The optima combination of process parameters for minimum Metal removal rate is obtained cutting speed 40 m/min, servo feed 2100 mm/min and servo voltage 20 v voltage.
3. ANOVA shows that the cutting speed has great influence for the response Metal Removal rate (MRR) and its percentage contribution to the metal removal rate is determined to be
4. Using the experimental data, a multi linear regression model is developed and the values obtained for the response MRR is compared with measured values. A graph was plotted between Regression predicted values and experimentally measured values and shows that the models are adequate without any violation of independence or constant assumption.

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