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Parametric Study of Nimonic Materials Machining by Wire Cut EDM Machine (WEDM)

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Abstract: ***Wire-electro discharge machining (WEDM) has emerged as a crucial non-traditional machining technique since it offers a practical approach for manufacturing components made from challenging materials such as titanium and zirconium, as well as for creating complex shapes that conventional machining methods cannot achieve. In this study, an experimental analysis has been conducted to assess how the parameters of Wire EDM influence the performance characteristics. A medium carbon steel AISI 1040 was chosen as the workpiece for this investigation due to its elevated ultimate tensile strength and hardness. The Wire EDM parameters for the experiments were organized according to the L16 0A design, using brass wire as the electrode and distilled water as the dielectric fluid. The results of AHP with utility analysis revealed that wire tension is the most influencing factor in achieving better multiple responses.***

Keywords: Wire EDM, machining parameters, AISI 1040 steel, utility analysis, wire tension

1. Introduction

New materials, which are created or required by technology from the space age, often cannot be economically processed using traditional cutting tools. Specialized super-hard materials, which are typically quite costly, are necessary. While synthetic diamonds or nearly impossible-to-grind diamond compounds are very expensive, they can be effectively cut using WEDM. This process minimizes material waste due to its narrow kerf width and the ability to accurately shape unusual designs. In contemporary manufacturing, WEDM is widely utilized to machine intricate shapes from advanced materials with high precision. WEDM is one of the most prevalent non-conventional machining techniques and is extensively applied in creating dies and molds for component production across various industries. The primary benefit of WEDM lies in its ability to create highly intricate shapes with great precision, regardless of the material's mechanical characteristics (notably hardness, brittleness, and strength). Wire EDM employs electrode tool wires made of brass, tungsten, or copper. Deionized water serves as the dielectric fluid. Similar to traditional EDM, the wire experiences erosion and is gradually fed. While it resembles conventional EDM, this method operates significantly faster due to higher currents and reduced rest periods. In recent years, rapid developments in aerospace, medical instruments, transportation, and many other industrial sectors increased the need for new materials with favorable characteristics. In addition to unique characteristics, most modern materials need special manufacturing processes to enable them to be machined with ease [1, 2]. Most of these materials are usually difficult to cut by conventional manufacturing processes [3-7]. The unique characteristics of these hard-to-cut materials increase their applications, which further drive manufacturers to explore new machining processes with reasonable cost and high precision [8, 9]. Tool steels and other tool materials (e.g., carbides) are such widely used hard-to-cut materials because of their high hardness and abrasion wear resistance, in addition to their ability to withstand high load and to operate in rapidly changing temperatures [6]. Tool steels have a wide range of applications, including stamping and metal-working dies, cutting tools, hammers, and machine parts [10]. Applications of these tools in the manufacturing sector is very large; thus, there exists huge machining requirements of tools, tooling, dies, and molds [11]. Before being put to use, these steels are subjected to heat treatment to meet the required properties for specific application [12, 13]. In addition to iron and carbon, tool steels have in them other elements (e.g., Cr, W, V, Mo, etc.) to increase their strength, hardness, hot strength and hot hardness, and wear resistance. Although these steels can be machined by conventional methods, they come with serious concerns with regard to very poor tool life and part accuracy [14]. Electric discharge machining (EDM) is one of the most advanced manufacturing methods used to successfully machine conductive hard-to-cut materials [8, 15-19]. EDM is the process of choice to machine hard-to cut materials widely used in modern industries to facilitate accurate machining [20-25], complex shape machining, and better surface integrity. The process is utilized to machine electrically conductive materials by applying repetitive sparks between electrode and work piece. Unlike in mechanical machining, no deforming force is required between the electrode and the work piece, and the machining takes place without actual contact between them [23, 26-28]. There are a large number of variants of the EDM process such as sinking EDM, wire EDM, micro-EDM, powder-mixed EDM, and dry EDM; all of these possess work on the same mechanism of material removal. Developments of variants make the process more versatile and suitable for relatively big and micro-scale machining areas. Several review papers related to EDM were published in recent years such as references [29-35], among others. Furthermore, some other articles presented a discussion of specific objectives; for example, Barenji et al. [36] developed a model for prediction of material removal rate (MRR) and tool wear rate (TWR) for the EDM of AISI D6 tool steel. The aim of this works a study of material removal mechanism in Wire Electro Discharge Machining (WEDM) process and optimization of performance characteristics has been undertaken keeping into consideration the following problems such as pulse on time, pulse off time, voltage, current and other machining parameters.

2. Experimental Details

In the present work a medium carbon and medium tensile steel called AISI 1040 as shown in figure 4.1 was taken as the work piece. AISI 1040 steel is suitable for the engineering applications where higher tensile strengths are required. It is used for shafts, gears, spindles, axles, bolts & studs, automobile parts and etc. The chemical composition and mechanical properties of AISI 1040 steel are given in tables 1 and 2 respectively. For machining CNC WEDM (ELECTRONICA Hitech, JOB MASTER D-ZIRE) was used. Brass wire of 0.25 mm and distilled water are used as electrode and dielectric fluid.

2.1 Range of process parameters

The pilot experiments were carried by varying the process parameters Flushing Pressure (F.P) Pulse-On-Time (TON), Pulse-Off-Time (TOFF), Servo Voltage (SV), Wire Feed (WF) and Wire Tension (WT) to study their effect on output parameters Surface Roughness (Ra) and Material Removal Rate (MRR). The ranges of these process parameters are given in Table 2. From these ranges of the process parameters, different levels of process parameters (Table 3) would be selected for the Taguchi experimental design and the experimental design using MINITAB i.e. L16 OA is given in the table 4.

Table 1. Chemical Composition of AISI 1040

Element	Composition (%)	Reference Range (%)
C	0.40	0.36-0.44
Si	0.25	0.10-0.40
Mn	0.80	0.60-1.00
S	0.05	0.05
P	0.05	0.05

Table 2. Process Parameters and Their Ranges

S.No.	Parameter	Range	Units
1	Pulse-On-Time (TON)	115-131	µsec
2	Pulse-Off-Time (TOFF)	40-63	µsec
3	Peak Current (IP)	180-230	Ampere
4	Spark Gap Voltage	10-20	Volts
5	Wire Feed (WF)	0-10	m/min
6	Wire Tension (WT)	0-5	Kg-f
7	Flushing Pressure (F.P)	3-15	Kg/cm2

Table 3. Process Parameters and Their Levels

Parameter	Units	Level-1	Level-2	Level-3
Flushing Pressure (F P)	Kg/cm2	4	8	_
Pulse-On-Time (TON)	µsec	115	120	125
Pulse-Off-Time (TOFF)	µsec	55	58	61
Wire Feed (WF)	mm/min	2	3	4
Wire Tension (WT)	Kg-f	2	4	6
Servo Voltage (S V)	Volts	20	25	30

Table 4. L16 Orthogonal Array (OA)

S.No	F P (Kg/cm2)	TON (µsec)	TOFF (µsec)	WT (Kg-f)	WF (mm/min)	SV (Volts)
1	4	115	55	2	2	20
2	4	115	58	4	3	25
3	4	115	61	6	4	30
4	4	120	55	2	3	25
5	4	120	58	4	4	30
6	4	120	61	6	2	20
7	4	125	55	4	2	30
8	4	125	58	6	3	20
9	4	125	61	2	4	25
10	8	115	55	6	4	25
11	8	115	58	2	2	30
12	8	115	61	4	3	20
13	8	120	55	4	4	20
14	8	120	58	6	2	25
15	8	120	61	2	3	30
16	8	125	55	6	3	30

2.2. Material Removal Rate (MRR)

For WEDM, MRR is a desirable characteristic and it should be as high as possible to give least machine cycle time leading to increased productivity. In the present study MRR is calculated as

$$MRR = \frac{Weight\ loss\ due\ to\ machining}{(Density\ of\ the\ material \times machining\ time)}$$

$$MRR = K \times t \times Vc \times p,$$

Where, K = kerf width mm, Vc= cutting speed m/s, ρ = density of material kg/m^3, t = thickness of material mm.

2.3. Surface Roughness

With contact-type surface roughness instruments, a stylus tip makes direct contact with the surface of a sample. The detector tip is equipped with a stylus tip, which traces the surface of the sample and electrically detects the vertical motion of the stylus. To precisely measure delicate shapes and roughness with a contact-type surface roughness tester, the radius of the stylus tip must be as small as possible with low contact pressure.

2.4 Taguchi Design

Dr. Genichi Taguchi is the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. Taguchi proposed several approaches to experimental designs that are called "Taguchi Methods." These methods utilize two-, three-, four-, five-, and mixed-level fractional factorial designs. Taguchi refers to experimental design as "off-line quality control" because it is a method of ensuring good performance in the design stage of products or processes.

3. Results and Discussion

The measured results of both material removal rate and surface roughness characteristics were tabulated in table 5. In the present work, in order to determine the weights of each criterion, a pair wise comparison matrix as shown in the table is developed using Analytical hierarchy process (AHP).

Table 5. Experimental Results

S.No	Voltage (V)	Ton (µs)	Toff (µs)	Wire Feed (m/min)	Current (A)	M/c Feed (mm/min)	Kerf Width (mm)	Ra (µm)	MRR (mm^3/min
1	40	7	2	4	2.1	3.1	0.290	1.75	45.52
2	40	8	4	6	2	3.3	0.293	1.39	31.29
3	40	9	6	8	1.8	2.8	0.288	1.22	23.70
4	40	10	8	10	1.2	2	0.283	2.10	18.42
5	45	7	4	8	2.5	2.7	0.280	1.56	31.24
6	45	8	2	10	2.2	2.5	0.290	2.88	34.88
7	45	9	8	4	1.5	2.5	0.294	1.61	17.01
8	45	10	6	6	1.8	2.8	0.297	1.24	19.26
9	50	7	6	10	2.2	3.4	0.295	4.32	25.77
10	50	8	8	8	1.9	2.8	0.304	1.62	16.56
11	50	9	2	6	2.1	2.7	0.284	1.63	27.43
12	50	10	4	4	2	3.5	0.314	1.88	22.56
13	55	7	8	4	2	3.3	0.310	2.11	22.48
14	55	8	6	6	2	3	0.316	1.46	26.34
15	55	9	4	10	2.1	3.1	0.301	1.55	24.77
16	55	10	2	8	2.1	2.6	0.300	1.25	24.29

The criterion weights are obtained as WMRR = 0.25 and WRa = 0.75 respectively. The value of CR is calculated as 0.0% which is less than the allowed value of CR (=0.1), indicating the fact that there is a good consistency in the judgments made by the decision maker while assigning values in the pair wise comparison matrix. The influences on MRR, Surface Roughness and kerf width is analyzed based on factors like discharge current, pulse duration, diameter of brass wire, is most important with help of Taguchi method. The response table for MRR Surface Roughness and kerf width are shown in Table 4 along with the input factors. In this investigation, the effects on material removal rate (MRR), surface roughness, and kerf width are determined by varying WEDM essential parameters such as peak current (A), Pulse on time (Ton), Pulse off time (Toff) and gap voltage (V).The experimental data were transferred to grey relational grade and were assessed using analysis of variance (ANOVA) for determining the significant and optimal combinational levels of machining parameters to achieve multiple performance characteristics. So, in WEDM optimal machining parameters were established for achieving high MRR, good surface roughness and kerf width for difficult to machine materials. In this work, grey relational analysis was adopted to evaluate the multiple performance characteristics of MRR, kerf width (Figure.1) and Surface Roughness for D2 die steel materials. The grey relational grade refers to the overall evaluation of experimental data for the performance characteristics using L16 orthogonal array which is represented in the Table 5. From this above array table, we have chosen the orthogonal array of L-16 based on 5 factors such as pulse on time, pulse off time, peak current, wire material, work piece material. Minitab 17 software was used for graphical analysis of the obtained data.

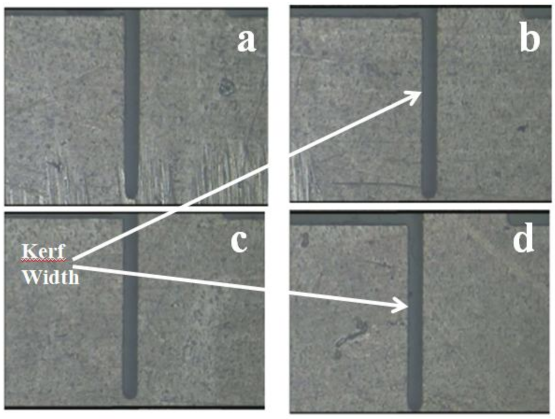

Fig.1. Shows Kerf width by VMS image

The WEDM process is not stable because of various condition of parameters may be voltage and current in the process as shown in Figure 3. The material erodes by means WEDM process which is attribute from the work piece normalise in discrete sparks between the work and the tool electrode immersed in the liquid dielectric medium. These electrical discharges melt and vaporize minute amounts of the work material, which are then ejected and flushed away by the dielectric fluid. MRR directly increases with increase in pulse on time (Ton) and peak current (IP) while decreases with increase in pulse off time (Toff) and servo voltage (SV). The results of optimization indicate that the MRR and surface finish are influenced more by pulse peak current, pulse duration, pulse off period and wire feed than by flushing pressure and wire tension. Results also indicate that the surface quality decreases as the MRR increases and they vary almost linearly. Material removal rate increases with proportionate increasing the pulse duration due increase pulse energy. Kerf is one of the important performance measures in WEDM. Kerf is the measure of the amount of the material that is wasted during machining. It affects the dimensional accuracy of the finished part. Kerf width appearance measured on work piece depends on gap voltage, pulse on time, pulse off time, wire feed and flushing pressure. It is measured in millimetres (mm).

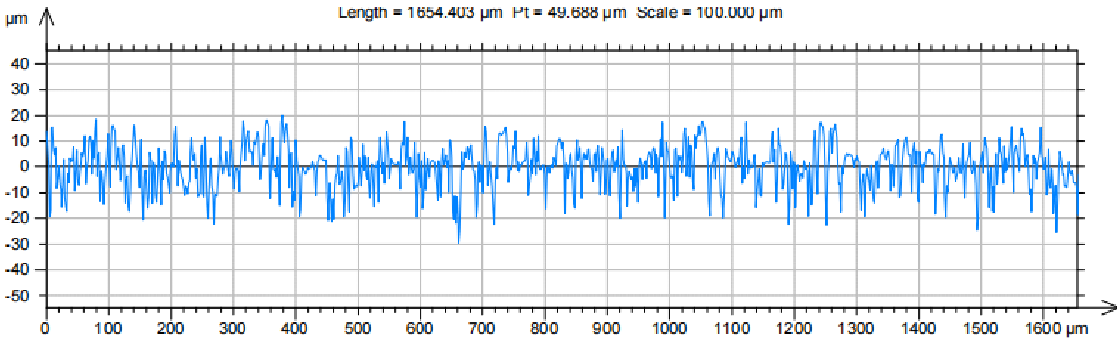

Figure 2. Surface roughness profilograph

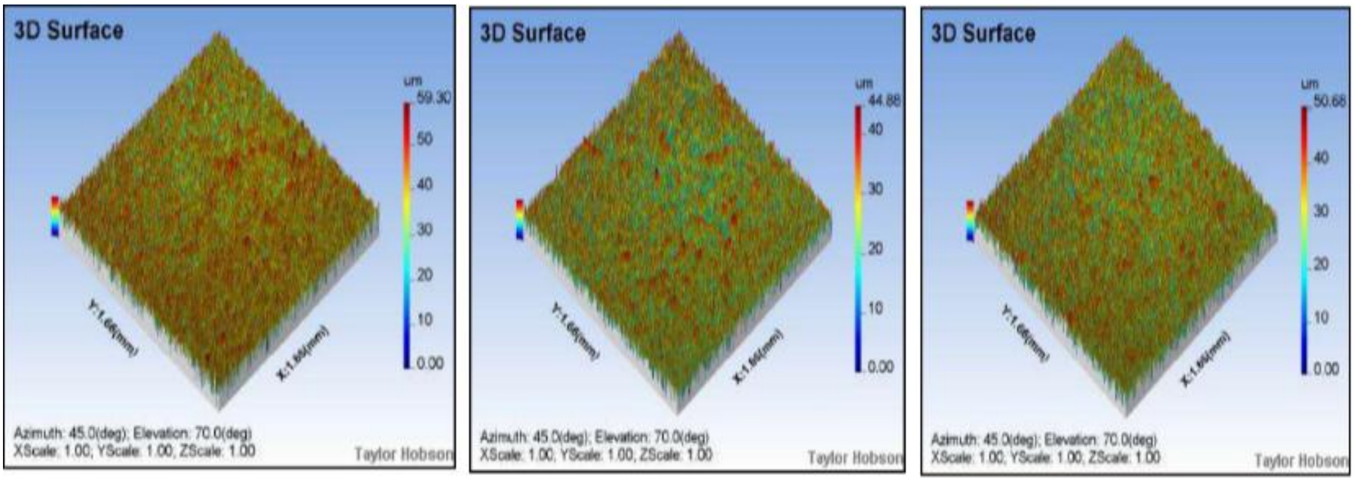

Figure. 3. Surface roughness 3D image profile

Figure 3 shows the surface roughness decreases upon increasing Pulse on Time and increasing upon increasing Pulse off time and Peak Current. Based on the input parameters, we can achieve minimal Surface Roughness (SR). MRR increases upon variables Pulse off Time and Peak Current. By choosing the input parameters are optimizing, we can achieve minimal increasing wear rate under controlled condition. Surface roughness increases with increase in current density. As the current increases surface of the final product becomes more and more rough. With the current increases from 1.9 ampere to 2.9 ampere surface roughness nominal value increases from 1.83 to 3.1 µm. Also, current and surface roughness relationship can be graphed as shown in Figure 3. As the pulse on time 35 increases, the surface roughness increases due to increase in the frequency of sparking. In the other words, double sparking and localized sparking become more frequent as the pulse on time increases. Double sparking produces a poor surface roughness. Pulse on time followed by peak current has significant effect on surface roughness. Increase in these parameters produce poor surface finish. Kumar et al confirmed in wire electric discharge machining of Ni based super alloy the larger pulse on time and peak current will cause to double sparking which increase surface roughness in machining. The grey relational grade represents the level of correlation between the reference sequence and the comparability sequence; the greater value of the grey relational grade means that the comparability sequence has a stronger correlation to the reference sequence. Based on grey relational grade value were given by average response in table 3. In this table, higher grey relational grade from each level of factor indicates the optimum level. The Pulse on time (10 µs), Pulse off time (4 µs) and Servo voltage (60 volts) respectively. The above graph between Pulse on Time, Pulse off Time with determine the MRR and Surface roughness value increased and decrease based on optimization parameters. In this parameter were determine the characterization of materials Ni based super alloy and high material removal rate also identified. The effects of discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate in wire electric discharge machining of Ni based super alloy using on coated copper wire with 0.25 mm diameter on surface roughness and material removal rate. It indicated that factors like discharge current, pulse duration, dielectric flow rate and their interactions play a significant role in surface roughness and material removal rate. It is the measure of the amount of the material that is wasted during machining and determines the dimensional accuracy of the finishing part. For present experiments kerf width has been measured. Figure 4, represented in using of the T (off) input parameters in machining process is to finally show of kerf width of die steel materials. Figure 5 plot slightly increased linear graph when operate machining in T (off) mode operations.

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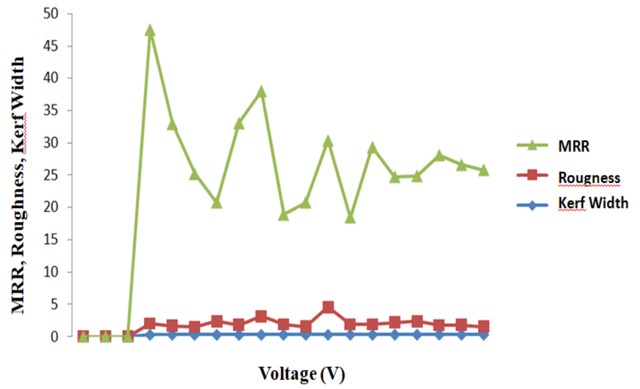

Figure 4. Chart representation of MRR, Roughness and Kerf Width

From Figure 4, it can be seen that for a particular value of input parameter the corresponding range of occurrence of kerf width can be determined and vice versa. It is established optimization techniques was revealed that give better performance results by which machining in the EDM process. The experimental results were confirmed to achieve the both MRR and surface roughness at increasing current and decreasing voltage, if the condition of machining performance. The Figure 5 shows express with the analysis of variance between MRR and Kerf width. Finally, the taguchi's techniques is to investigated the parameters like pulse on time, pulse off time, peak current, servo voltage and servo feed on MRR and surface roughness on die steel using Wire-cut EDM process. Figure 11 shows small gap of cutting by wire under parameter at this room condition. According to ANOVA the most significant parameters with respect to Kerf width are discharge voltage (A), capacitance (B), feed rate (C) interaction of voltage From the Figure, it can be concluded that Kerf width can be achieved using low discharge energy and constant stable discharge circumstance. This will be improving the dimensional accuracy and reduction of material removal while cutting a corner in micro-machined components. It is also observed that increase in the voltage leads to an increase in discharge energy and hence Kerf Width (KW) increases. Similarly, the KW tends to increase with increase in capacitance and also at some point KW decreases.

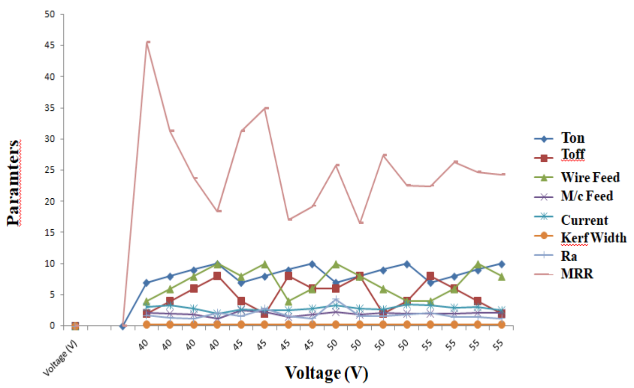

Figure 5. Comparison chart with Wire EDM parameters

Figure 5 shows the two-dimensional contour plot of voltage and capacitance when feed rate remains fixed velocity at these conditions. The shows the 16 number of trail specimen investigated against surface roughness and kerf width. Normally, the kerf width value has been produced significantly in the various cutting parameters in WEDM process. Depends upon the parameters were achieved different kind of value between 0.265 and 0.306 mm has obtained in the EDM process. Similarly, the corresponding roughness value also varied at the condition of input parameters. The surface roughness was calculated in the 16 specimen is noted in the range of 1.16 and 4.06 microns significantly. Due to the condition of speed, feed, depth of cut, servo voltage and current parameters value were changed while machining operation in the condition of surface value is varied in the WEDM process.

4. Conclusion

The present work discussed an application of taguchi based Utility method and AHP for investigating the effects of Wire EDM parameters on material removal rate and surface roughness in Machining of AISI 1040 steel. From the results of Utility analysis and ANOVA the following conclusions can be drawn: From the Utility analysis, the optimal combination of machining parameters is obtained at Flushing Pressure (FP): Level 1: 4 kg/cm^2

Pulse -On
Pulse-Off
Wire Tension (WT): Level 1: 2 kg-f
Wire Feed (WF): Level 1: 2 mm/min
Servo Voltage (SV): Level 3: 30Volts

ANOVA results concluded that the Wire Tension is the most influencing parameter on the multi-responses.

The errors are distributed normally and they are not following any regular patterns hence following the assumptions normality and constant variance of ANOVA. The model prepared for the overall utility (Ui) is the best fit and it can be accurately used for the prediction of multiple responses.

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