Optimization of surface roughness and MRR on Inconel 738 alloy machined by wire cut EDM

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***Abstract* - Wire electric discharge machining (WEDM) is an important technology, which demands high-speed cutting and high-precision machining to realize productivity and improved accuracy for automotive, manufacturing of press stamping dies, prototype parts etc. Manufacturing advances in Electrical discharge machining (EDM) wires have directly contributed to increased cutting speed and dimensional accuracy. Moreover, investigations of cutting performance with pulse on time, pulse off time, servo voltage, wire feed, current and cutting speed were experimentally investigated in WEDM process. Brass wire with 0.25mm diameter and Inconel 738 with 575 x 835 x 200 mm were used as tool and work materials in the experiments. The cutting performance outputs considered in this study are material removal rate (MRR) and surface roughness. Experimentation has been completed by using Taguchi's L16 orthogonal array under different conditions of parameters. Optimal combinations of parameters were obtained by this technique. This study shows that the complete problem can be solved with the minimum number of experiments when compared to full factorial design. The results obtained are analyzed for the selection of an optimal combination of WEDM parameters for proper machining of Inconel 738 to achieve better surface roughness and MRR**

***Index Terms* - Wire EDM, MRR, Surface roughness, Taguchi's method, ANOVA.**

1.INTRODUCTION

WEDM is widely used in most manufacturing industries due to its capability of producing complex geometric surfaces with reasonable accuracy and surface finish. A literature survey was made on the various optimization techniques that have been used in the Optimization of EDM process parameters. Eubank, P.T at.al. (2021) have instigated the recent up-gradation of newer and harder materials have made the machining task in WEDM quite challenging. Optimization of all resources is essential to make the optimum use of parameters to get the best output to increase productivity. Gokler, S.K.and Ozanozgu, A.M. (2020) reported that in WEDM, the material is eroded from the work piece by a series of discrete sparks occurring between the work piece and the wire separated by a stream of dielectric fluid, which I continuously fed to the machining zone. In recent years, the technology of WEDM has been improved significantly to meet the requirements in various manufacturing fields; especially in the precision die industry. WEDM has been improved significantly to meet the requirements in various manufacturing fields. especially in the precision die industry. Han.F. Jiang, J.and Dingwen, Yu (2021), discuss the optimization of W/Cu composite martial are used the Taguchi method W/Cu composites are a type of cooling material highly resistant to heat corrosion produced through powder metallurgy The Taguchi method and 1.18 orthogonal array to obtain the polarity, peak current, pulse duration, duty factor, rotary electrode rotational speed, and gap load voltage to explore the material removal rate, electrode wear rate, and surface roughness. Huang, J.T (2021), investigated the optimization of machining parameters used for EDM of Boron carbide of conductive ceramic materials. It is these conditions that determine such important characteristics as surface roughness, electrode wear, and MRR. Bhattacharyya Kanalayasiri, K.and Boonmung,S. (2018). Created a mathematical model for surface roughness, white layer thickness, and surface crack density based on response surface methodology (RSM). It emphasizes the advantages of developing comprehensive models for connecting the interaction and higher-order effects of main machining parameters, such as peak current and pulse-on duration, on various elements of surface integrity of M2 Die Steel machined by EDM. Kanalayasiri, K,and

Boonmung, S (2019) had proposed an effective process parameter optimization approach that integrates Taguchi's parameter design method, response surface methodology (RSM), a back-propagation neural network (BPNN), and a genetic algorithm (GA) on engineering optimization concepts to determine optimal parameter settings of the WEDM process under consideration of multiple responses. Material removal rate and work-piece surface finish on process parameters during the manufacture of pure tungsten profiles by wire electrical discharge machining (WEDM Kuriakose, S. and Shunmugam, M.S (2018) have presented the use of grey relational analysis based on an orthogonal array and the fuzzy-based Taguchi method for the optimization of the electrical discharge machining process with multiple process responses. Both the grey relational analysis method without using the S/N ratio and fuzzy logic analysis is used in an orthogonal array table in carrying out experiments. Experimental results have shown that both approaches can optimize the machining parameters (pulse on time, duty factor, and discharge current) with consideration of the multiple responses. Liao, Y.S.Huang J.T. and Chen, Y.H (2020) have proposed an application of theTaguchi method and grey relational analysis to improve the multiple performance characteristics of the electrode wear ratio, material removal rate, and surface roughness in the electrical discharge machining of Ti-6Al-4V alloy. The literature review reveals that the researchers have carried out most of the work on WEDM developments, monitoring, and control but very limited work has been reported on the optimization of process variables. Most of the researchers have investigated the influence of a limited number of process parameters on the performance measures of WEDM parts. Few researchers have already attempted several systematic procedures for optimizing the multiple responses of WEDM processes. There also exist some other approaches which may be quite effective for multi-response optimization of WEDM processes. Only a few of them use relatively simpler computations procedures and, therefore, are promising to the engineering for real-time application in the area of advanced manufacturing technology, the main focus is to achieve the best process/product performance so the selection of the most appropriate multi-response optimization method for a given WEDM process.

2. EXPERIMENTAL PROCEDURE

The experimental work using L16 orthogonal array based on Taguchi design. In this experimental setup the selection of work piece and taking all the values MRR, kerf width, and surface roughness is done.

Preparation of Specimens

The Inconel 738 super alloy mounted on the ELECTRONICA SPRINTCUT WEDM machine tool (Figure) and specimens of 5mmx5mmx15mm size are cut. The close close-up of plate blank used for cutting the specimens is shown mounted on the WEDM machine.

Process Parameters Selection

The experiments were carried out on a Wire Electro Discharge Machine (WEDM) (fig.1) ELECTRONICA ECOCUT of M/S Electronic Machine Tools Ltd. Installed at the Precision Engineering Lab of the Manufacturing Engineering Department. College of Engineering. Anna University Guindy, Chennai 25, Tamil Nadu, India. The discussions are related to the measurement of WEDM Experimental Parameters (table 1) like material Removal Rate (MRR), kerf width, and Surface Roughness and composition of work piece (table 2) mentioned below.

Sl. No.	Parameters	Range
1	Wire Material	Diffused Brass Wire
2	Wire Size (mm)	Ø 0.25
3	Wire Tension (gm)	1600
4	Die Electric	Deionized Water
5	Cable Feed Rate (mm/min)	80
6	Work Piece	Inconel 738 super alloy

Table 1:Process Parameters ofWire-EDM Process

Grade Wt.%	Ni	Cr	Co	Mo	W	Ti	Zr	Nb	Ta
Inconel 738	61	15	8	1.5	2.2	3	0.15	0.6	1.5

Table 2 : Work piece composition

Figure 1:Schematic diagram of basic principle of wire EDM

Material Removal Rate (MRR)

For WEDM, MRR is on a desired characteristic and it should be high as possible to give less machine cycle time leading to increased productivity in the present study MRR is calculated as MRR = K × t ×Vc × p Where, K = kerf width, Vc= cutting speed, ρ = density of material, t = thickness of material.

Surface Roughness

Roughness often determines the performance of a work piece or a component, since irregularities in the surface may cause defects like cracks or corrosion. Roughness is a measurement of the texture of a surface. It is qualified by the vertical deviations of a real surface from its ideal form. If the deviations are large the roughness value is high thus making the surface rough Lower the deviations of a surface lower will be roughness value thus making it a smooth surface. R is the parameter for surface roughness. The measurement is done for average roughness by comparing all the peaks and valleys to the means line and then averaging all over the entire cut-off length. Cut-off length is the length that the stylus is dragged across the surface. A larger cut-off length will give a better average value, and a shorter cut-off length might give a lesser average value.

Taguchi design experiments in MINITAB

MINITAB provides both static and dynamic response experiments in a static response experiment, the quality characteristic of interest ha fined level The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against sensitivity to) noise factors. MINITAB calculates response tables and generates main effects and interaction plots for:

- Signal-to-noise ratios (S/N ratios) vs. the control factors
- Means (static design) vs. the control factors:

3. RESULTS AND DISCUSSION

This chapter is related to the influences of MRR, Surface Roughness finding the result which factors discharge current, pulse duration, and diameter of brass wire, is most important with help of the Taguchi method.

Design of experiment is an effective tool to design and conduct the experiments with minimum resources. Orthogonal Array is a statistical method of defining parameters that converts test areas into factors and levels. Test design using orthogonal array creates an efficient and concise test suite with fewer test cases without compromising test coverage. In this work, L16 Orthogonal Array design matrix is used to set the control parameters to evaluate the process performance. The Table 3 shows the design matrix used in this work.

Specimens of 5mmx5mmx5mm size are cut by WEDM process with the help of brass wire on Inconel 738 as work piece material for each combination of parameters considered according to the Orthogonal Array. To calculate the material removal rate and the electrode consumption standard formulas are used and the surface roughness.

The kerf is expressed as the sum of the wire diameter and twice the wire workpiece gap. The kerf (cutting width) used to find the metal removal rate determines the accuracy of the finishing part. The gap between workpiece usually ranges from 0.25 to 0.75mm and is constantly maintained by the computer controlled positioning system which is 0.27 for our work. Using the cutting speed values in the formula the Metal Removal Rate (MRR) was estimated and the values are given in the table 4

Experiment No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

Table 3. Experimental design using L16 orthogonal array

The kerf is expressed as the sum of the wire diameter and twice the wire work piece gap. The kerf (cutting width) used to find the metal removal rate determines the accuracy of the finishing part. The gap between work pieces usually ranges from 0.25 to 0.75mm and is constantly maintained by the computer-controlled positioning system which is 0.27 for our work. Using the cutting speed values in the formula the Metal Removal Rate (MRR) was estimated and the values are given in the formula. The response table for MRR Surface Roughness and kerf width is 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, and Surface Roughness for Inconel 738 super alloy. The grey relational grade refers to the overall evaluation of experimental data for the performance characteristics using L16 orthogonal an array which is represented in table 5

Factor	parameter	Level	Level	Level	Level
A	Gap	40	45	50	55
B	Pulse on	4	4	4	4
C	Pulse off	2	4	6	8
D	Applied	1.9	2.1	1.5	1.8

Table 4: Factors and their levels Inconel 738 super alloy

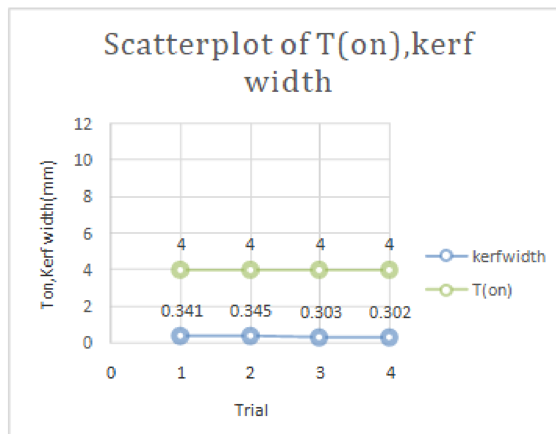


Figure 2 : Graph plot between T(on)and response variables

MRR= K × t × V c × ρ

Here k is the kerf width (mm)

t is the thickness of the work piece (10 mm),

Ve is the cutting speed in (mm/min)

D is diameter of wire (mm)

Sl/No	Voltage	Ton	T Off	Wire Feed	Current	M/C Speed	Time	Kerf width	Ra	MRR
1	40	4	2	1	1.9	2.3	9.21.17	0.341	1.98	42.57
2	40	6	4	2	1.7	2.1	8.03.30	0.379	2.01	29.32
3	40	8	6	3	1.8	2.3	7.10.61	0.332	1.82	23.8
4	40	10	8	4	2.1	2.4	7.34.94	0.325	2.5	15.41

5	45	4	4	3	1.9	2.2	7.30.47	0.345	1.75	30.95
6	45	6	2	4	2.1	2.2	8.10.47	0.349	2.72	35.97
7	45	8	8	1	1.9	1.7	8.52.30	0.323	2.23	16.38
8	45	10	6	2	1.9	2	8.14.75	0.338	1.88	18.36
9	50	4	6	4	1.5	1.7	9.57.19	0.303	1.95	26.88
10	50	6	8	3	1.5	1.6	10.20.80	0.29	2.02	17.37
11	50	8	2	2	2.1	2.4	7.10.89	0.302	1.84	28.32
12	50	10	4	1	1.9	2.2	7.24.94	0.319	1.88	24.3
13	55	4	8	2	1.8	1.9	9.28.83	0.302	1.67	18.17
14	55	6	6	1	1.8	2	9.19.38	0.328	1.64	22.48
15	55	8	4	4	1.5	1.9	8.40.58	0.347	1.71	25.74
16	55	10	2	3	1.8	2.2	7.46.22	0.332	1.8	25.91

Table 5: Response table

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. It is evident from the results that, MRR increases upon increasing Pulse on Time, Pulse off Time, Pulse Peak Current. We can achieve the nominal output response (i.e. Max MRR, Min SR and best kerf width (Fig.2)). The change in relevant input parameters can achieve maximum Metal Removal Rate (MRR) good surface finish and kerf width. Surface Roughness decreases upon increasing Pulse on Time, Pulse off time and Peak Current. Based on the input parameters, we can achieve minimal Surface Roughness (SR). MRR increases upon increasing variables like Toff and peak current. By appropriate selection of optimal input parameters, we can achieve minimal increasing wear rate under controlled condition. Surface roughness increases with increase in current density. When the current increases, surface of the final product becomes more and more rough. When current increases from 2 ampere to 3 ampere surface roughness nominal value increases from 16 to 18 pm. Also, current and surface roughness relationship can be graphed as shown in shone figure 3. Material removal rate decreases with increase in current density. As current density increases, material removal rate decreases. From figure 4 as current density is 40 amperes, material removal rate decreases from 40 to 30 mm3/minute. Based on the current densities and increase of current causes temperature variation between the electrodes and work-piece due to which vaporization of work piece takes place. The graph between material removal rate and Kerf width is shown in figure 5, 6 and 7.

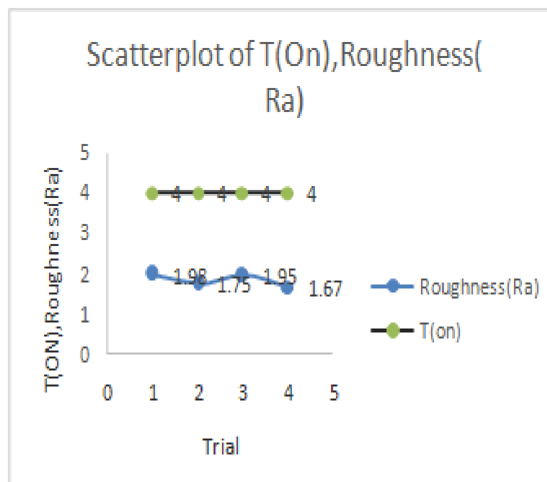


Figure 3: Graph plot between T(on) and Roughness

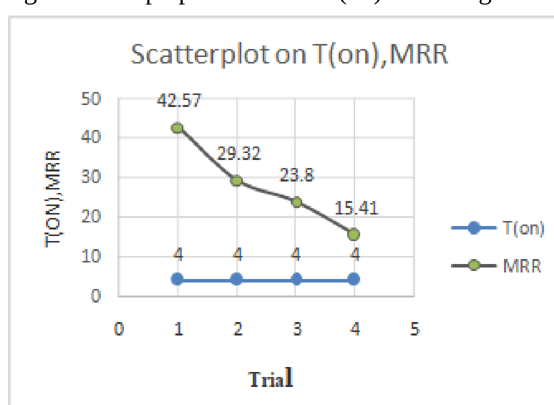


Figure 4: Graph plot between T(on) and MRR

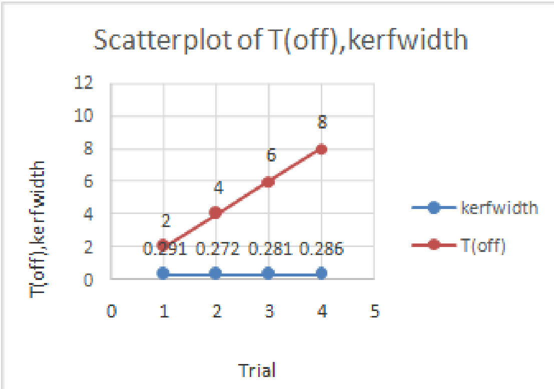


Figure 5: Graph plot between T(on) and Kerf width

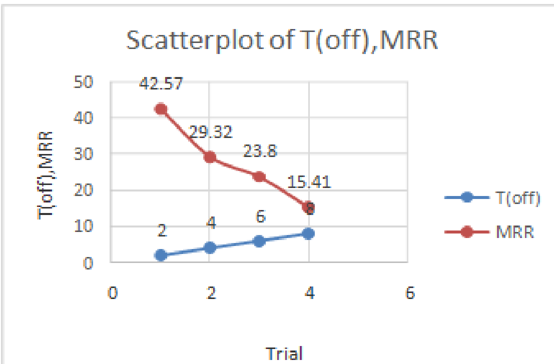


Figure 6: Graph plot between T(off) and MRR

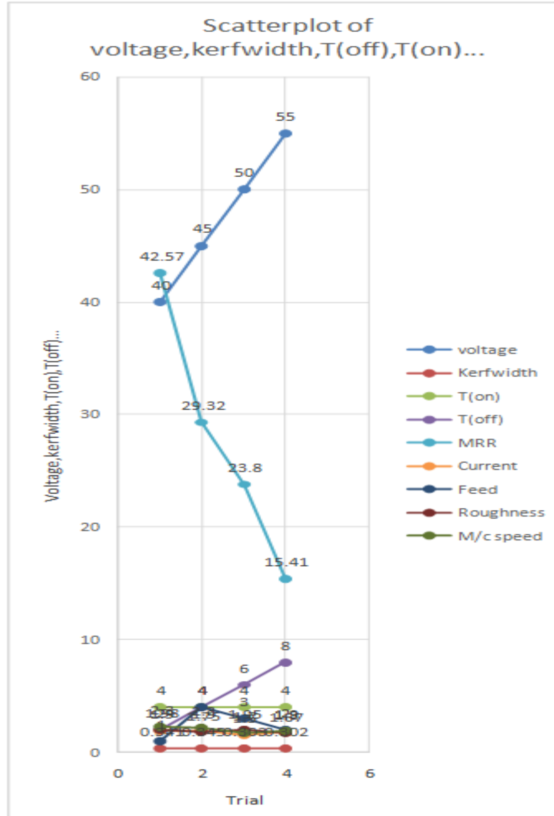


Figure 7 : Comparison chart of Wire-EDM Parameters

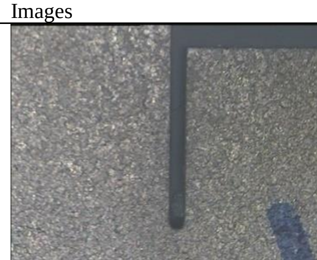
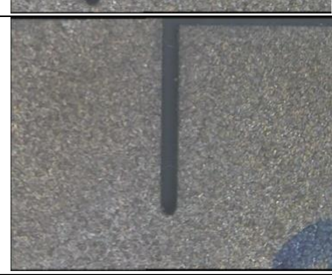
Experiment No	Kerf width (mm)	Roughness (Microns)	Images	VMS Images
1	0.341	1.98		
2	0.379	2.01		
3	0.332	1.82		

Table show specimens with Roughness and kerf width values by VMS

4. CONCLUSION

In the presented work, experiments are carried out for material removal rate, surface roughness and KERF width with variables as pulse on time, pulse off time and servo voltage. There are16 experimental readings taken for all variables to conduct the parametric study. Finally, it can be concluded that: Grey relational analysis is done to find out optimal parameter levels. After grey relational analysis, it is found that pulse on time at level 3 (10µs). pulse off time at level 3 (4 us), servo voltage at level 2 (60volts) are the best process parameter for the MRR, KERF width and Surface roughness. Process parameters do not have some little effect for every response. The significant parameters and its percentage contribution changes as per the behaviour of the parameters with objective response. Increase of Pulse on time generates more spark energy as the length of time that electricity supply increases. MRR, KERF width and Surface Roughness. all response increasing with pulse on time. Pulse on time found most significant parameter in all response. Surface roughness also increases with increase of pulse on time because the increases of pulse on time produce crater with broader and deeper characteristic. Pulse off time has opposite effect to pulse on time. MRR decrease with increase of pulse of metal removal rate, minimization of electrode consumption and minimization of surface roughness Taguchi's experimental design (L16 orthogonal array) is used to obtain the optimum machining parameters for the maximization of metal removal rate, minimization of electrode consumption and minimization of surface roughness. over MRR. Surface roughness reduces with increase of servo voltage. Factors like the pulse duration and the feed rate have been found to play as significant role in rough cutting operations for the maximization off time better the flushing.

5.FUTURE WORK

Although the WEDM machining has been thoroughly investigated for Inconel 738 super alloy work material, still there is a scope for further investigation. The following suggestions may prove useful for future work:

- The effect of process parameters such as flushing pressure, conductivity of dielectric, wire diameter, work piece height, electric flow rate etc. may also be investigated.
- Other performance criteria such as the skewness, waviness and white layer depth of the wire electro- discharge machined job surface might be investigated using the same approach presented here.
- Efforts should be made to investigate the effects of WEDM process parameters on performance measures in a cryogenic cutting environment.

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