Modeling and Optimization of WEDM Process Parameters on Machining of AISI D2 using Taguchi Method

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Abstract

Since it is frequently used for die-punch development and the machining of hard, brittle materials, wire electric discharge machining, or WEDM, is a commonly used machining method in various industries. When producing complicated shapes, WEDM is also utilized. The choice of the right machining factors has a significant impact on how well the WEDM machining process performs. One method utilized in the manufacturing sector to find the ideal circumstances for production is optimization, which is crucial for firms hoping to produce high-quality goods at lower costs. The WEDM machining process involves a large number of process variables, making it challenging to select the right mix of these variables to optimize material removal rate while reducing tool wear and surface roughness. The aim of this study is to examine the impact of process variables, including wire feed, servo voltage, peak current, pulse on and off times, and Surface roughness, gap voltage, gap current, and cutting rate, on performance metrics in the WEDM machining process. The WEDM process's impacts on process parameters are estimated, and a set of ideal parameters for the process's best performance is predicted, using the Taguchi technique. To determine the degree of importance of each process parameter in each case, ANOVA has been used. This technique has the potential to greatly improve process performance, as demonstrated by experimental verification of the obtained results

Keywords: ANOVA, Inconel718, Microstructure, Selective Laser Melting, Taguchi, Porosity, Hardness

1. Introduction

Wire Cut Electro Discharge Machining (WEDM) technology has grown tremendously since it was first applied more than 30 years ago. D.H. Dulebohn used the optics-based line follower arrangement to have control over shape of the components that are to be machined by the WEDM process mechanically. By 1975, popularity of WEDM rapidly increased, as the machinery along with its capabilities were well understood by the industry in better way. It was only at the end of the 1970s, when Computer Numerical Control and development system was incorporated into WEDM, which bought about major evolution of the machining process. The WEDM machine comprises of a main worktable (X-Y) on which the work piece is clamped; and auxiliary table (U-V) and wire drive mechanism. The main table moves along X and Y-axis and it is driven by D.C. servo motors. The travelling wire fed is continuously fed from wire feed spool and gets collected again on take up ring which moves across the work piece is supported by tension between wire guides located at the opposite side of the work piece. The lower wire guide ring at rest is stationary whereas the upper wire ring, supported by U-V table, can be moved transversely along U and V-axis with respect to lower guide ring. The upper wire guide can also be mounted vertically along Z-axis by moving the quill.

The region where discharge takes place gets heated to very high temperature, so that the surface gets converted into molten state & is removed. The removed particles are flushed away with the flowing dielectric fluids. The wire for WEDM is generally made of alloy having constituents as copper, brass, molybdenum and tungsten. Zinc or brass coated wires are also used widely in this process. The wire used in the have should possess good electrical conductivity and high tensile and mechanical strength shown in figure 1.

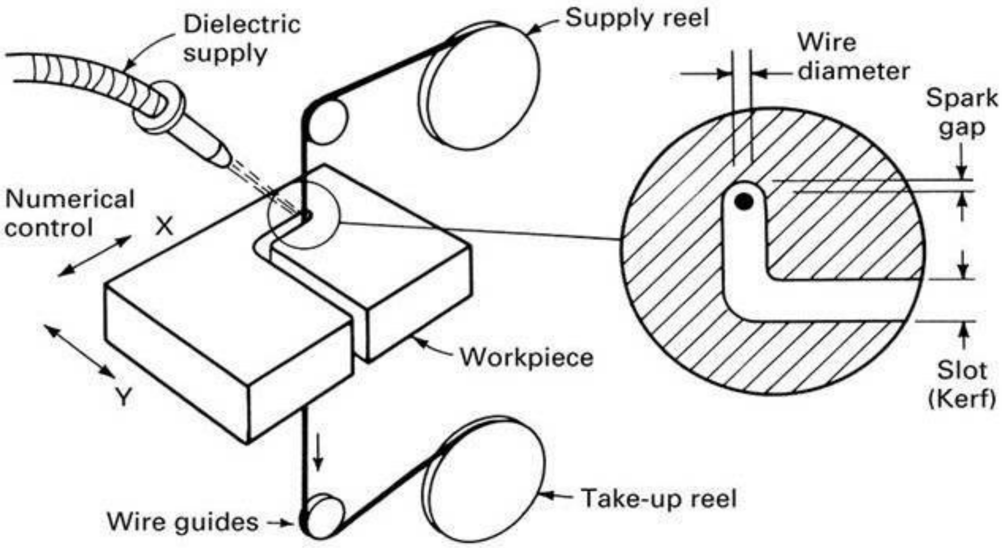

Figure 1: Schematic Diagram of Basic Principle of WEDM

2. LITERATURE REVIEW

A.Thillaivanan et at. 2023 In this paper the complexity of electrical discharge machining process which is very difficult to determine optimal cutting parameters for improving cutting performance has been reported. Optimization of operating parameters is an important step in machining, particularly for operating unconventional machining procedure like EDM. A suitable selection of machining parameters for the electrical discharge machining process relies heavily on the operators' technologies and experience because of their numerous and diverse range. Machining parameters tables provided by the machine tool builder cannot meet the operators' requirements, since for unarbitrary desired machining time for a particular job, they do not provide the optimal machining conditions. An approach to determine parameters setting is proposed. Based on the Taguchi parameter design method and the analysis of variance, the significant factors affecting the machining performance such as total machining time, oversize and taper for a hole machined by EDM process, are determined. Artificial neural networks are highly flexible modelling tools with an ability to learn the mapping between input variables and output feature spaces.

Ashish Srivastava et al. 2023 Surface finish and Metal removal rate (MRR) is one of the most prime requirements of customer and it is also a significant tool to reduce the cycle time of any machine operation as well as the overall cost of the production. In the recent years, quality of product is a essential demand of customer which turned to the fast and rapid technologies of production. This paper presents an experimental study on composite of Al2024 reinforced with SiC to investigate the effects of electric discharge machining (EDM) for three levels of each parameter such as current pulse on time and reinforcement percentage on surface finish and MRR.

A.K.M Asif Iqbal et al. 2023 Problem statement: Electrical Discharge Machining (EDM) has grown over the last few decades from a novelty to a mainstream manufacturing process. Though, EDM process is very demanding but the mechanism of the process is complex and far from completely understood. It is difficult to establish a model that can accurately predict the performance by correlating the process parameters. The optimum processing parameters are essential to increase the production rate and decrease the machining time, since the materials, which are processed by EDM and even the process is very costly. This research establishes empirical relations regarding machining parameters and the responses in analysing the machinability of the stainless steel. Approach: The machining factors used are voltage, rotational speed of electrode and feed rate over the responses MRR, EWR and Ra. Response surface methodology was used to investigate the relationships and parametric interactions between the three controllable variables on the MRR, EWR and Ra. Central composite experimental design was used to estimate the model coefficients of the three factors. The responses were modelled using a response surface model based on experimental results. The significant coefficients were obtained by performing Analysis of Variance (ANOVA) at 95% level of significance. Results

B. Bhattacharyya. 2022 In non-traditional machining processing, electrochemical machining (ECM) has tremendous potential on account of the versatility of its applications and it is expected that it will be successfully and commercially utilised in modern industries, although the effective utilisation of this machining technology will require the application of a system approach to solve some of the predominant machining problems. Because of various complex physico-chemical and hydrodynamic phenomena that occur in the machining gap.

Bijaya Bijeta Nayak and Siba Sankar Mahapatra 2022. The present work proposes an experimental investigation and optimization of various process parameters during taper cutting of deep cryo-treated Inconel 718 in wire electrical discharge machining process. Taguchi's design of experiment is used to gather information regarding the process with less number of experimental runs considering six input parameters such as part thickness, taper angle, pulse duration, discharge current, wire speed and wire tension. Since traditional Taguchi method fails to optimize multiple performance characteristics, maximum deviation theory is applied to convert multiple performance characteristics into an equivalent single performance characteristic.

Bikash Choudhuri et al. 2022 H21 steel is one of the hot work tool steels, which exhibits superior red hardness, high mechanical strength and difficult-to-machine. Wire electrical discharge machining (WEDM) always demands high-speed and high-precision machining to fulfill productivity and accuracy of machining hard materials. Cutting speed determines the productivity of machining and the width of kerf determines the tolerance of finished product. Two methodologies viz. response surface method (RSM) and artificial neural network (ANN) are compared for their modelling, sensitivity analysis and optimization abilities. The predictability of ANN model is better than RSM which indicating the advantage of ANN in mappingthe nonlinear behavior of the system.

Datta et al. 2021 In the present work, quadratic mathematical models have been derived to represent the process behaviour of wire electrical discharge machining (WEDM) operation. Experiments have been conducted with six process parameters: discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate; to be varied in three different levels. This indicates utility of the grey-Taguchi technique as multi-objective optimizer in the field of wire EDM. [9]

Deepak Rajendra Unune and Har Lal Singh Mali 2021. The micro-wire electric discharge machining (micro-WEDM) has emerged as the popular micromachining processes for fabrication of micro-features. However, the low machining rate and poor surface finish are restricting wide applications of this process. Therefore, in this study, an attempt was made to improve machining rate of micro-WEDM with low-frequency workpiece vibration assistance. The gap voltage, capacitance, feed rate and vibrational frequency were chosen as control factors, whereas, the material removal rate (MRR) and kerf width were selected as performance measures while fabricating microchannels in Inconel 718.

El-Taweel. 2021 The present study investigates the relationship of process parameters in electro-discharge of CK45 steel with novel tool electrode material such as Al–Cu–Si–TiC composite produced using powder metallurgy (P/M) technique. The central composite second-order rotatable design had been utilized to plan the experiments, and response surface methodology (RSM) was employed for developing experimental models. Analysis on machining characteristics of electrical discharge machining (EDM) die sinking was made based on the developed models. In this study, titanium carbide percent (TiC%), peak current, dielectric flushing pressure, and pulse on-time are considered as input process parameters.

G. Rajyalakshmi & P. Venkata Ramaiah. 2020 In this paper, an effective approach, Taguchi grey relational analysis, has been applied to experimental results of wire cut electrical discharge machining (WEDM) on Inconel 825 with consideration of multiple response measures. The approach combines the orthogonal array design of experiment with grey relational analysis. The main objective of this study is to obtain improved material removal rate, surface roughness, and spark gap. Grey relational theory is adopted to determine the best process parameters that optimize the response measures. The experiment has been done by using Taguchi's orthogonal array L36 ($2^1 \times 3^7$). Each experiment was conducted under different conditions of input parameters.

S. Gopalakannan et al. 2020. Experiments were carried out by adopting face cantered central composite design of response surface methodology. Analysis of variance was applied to investigate the influence of process parameters and their interactions viz., pulse current, gap voltage, pulse on time and pulse off time on material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). The objective was to identify the significant process parameters that affect the output characteristics and to develop for MRR, EWR and SR. [13]

J.Udaya Prakash et al. 2019 The objective of this work is to investigate the effect of parameters like gap voltage, pulse on time, pulse off time, wire feed and percentage reinforcement on the responses material removal rate as well as surface roughness while machining Aluminium alloy (A413)/flyash/boron carbide hybrid composites using Wire Electrical Discharge Machining (WEDM). Experimentation has been done on Taguchi's L_{27} orthogonal array under different combinations of parameters. Analysis of variance (ANOVA) has been used to determine the design parameters significantly influencing the response.

3. Experimental Setup and Procedure

3.1 Work piece material

The AISI – D2 steel has been used as a work piece material for the present experiments. AISI D2 is a high carbon, high chromium tool steel alloyed with molybdenum and vanadium characterized by:

- High wear resistance
- High compressive strength
- Good through-hardening properties
- High stability in hardening
- Good resistance to tempering-back.

Table 1: Chemical composition of metal powder

Element	**Composition (%)**
C	1.40 – 1.60
Mn	0.60
Si	0.60
Co	1.00
Cr	11.00 – 13.00
Mo	0.70 – 1.20

3.2 Machine tool used

The experiments were carried out on a wire-cut EDM machine (Electronica Ultracut S2) of Electronica Machine Tools Ltd. (shown in figure 4.1) installed at M/s. Bhagwati Textiles (P) Ltd. Bhilwara (Raj.).

Figure 1: Electronica Ultracut S2 WEDM Machine

3.3 Design of experiment

According to the Taguchi method, a robust design and an L27 orthogonal array are employed for the experimentation. Five machining input parameters of WEDM as mentioned in the objective of the works have been considered as controlling factors namely.

Table 2: Machining Parameters and their respective levels

Factors	Process Parameters	Levels		
		L1	L2	L3
A	Pulse on time (μ sec)	110	115	120
B	Pulse off time (μ sec)	45	50	55
C	Servo voltage (V)	20	30	50
D	Wire feed (mm/min)	2	4	6
E	Peak current (A)	50	100	150

4 Analysis and discussion of result

The WEDM experiments were conducted by using the parametric approach of the Taguchi‟s method. The effects of individual WEDM process parameters, on the selected quality characteristics – cutting rate, gap current, gap voltage, surface roughness, material removal rate, have been discussed in this section

4.1 Effect on Material Removal Rate

With objective to understand the effect of process parameters on the material removal rate, experiments were conducted using L27 Orthogonal array. The experimental data and their respectively S/N ratio for material removal rate.

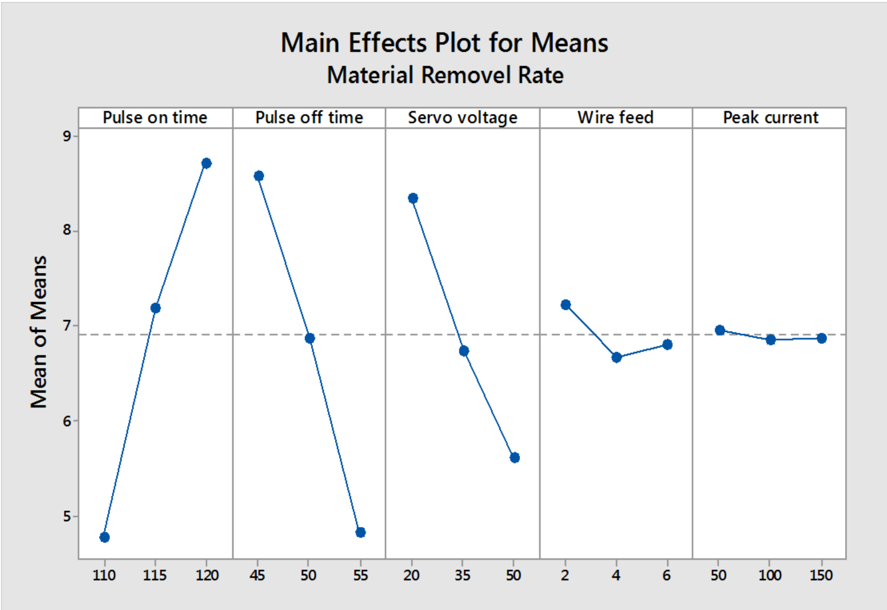

Figure 5.7: Effects of process parameters on material removal rate (raw data)

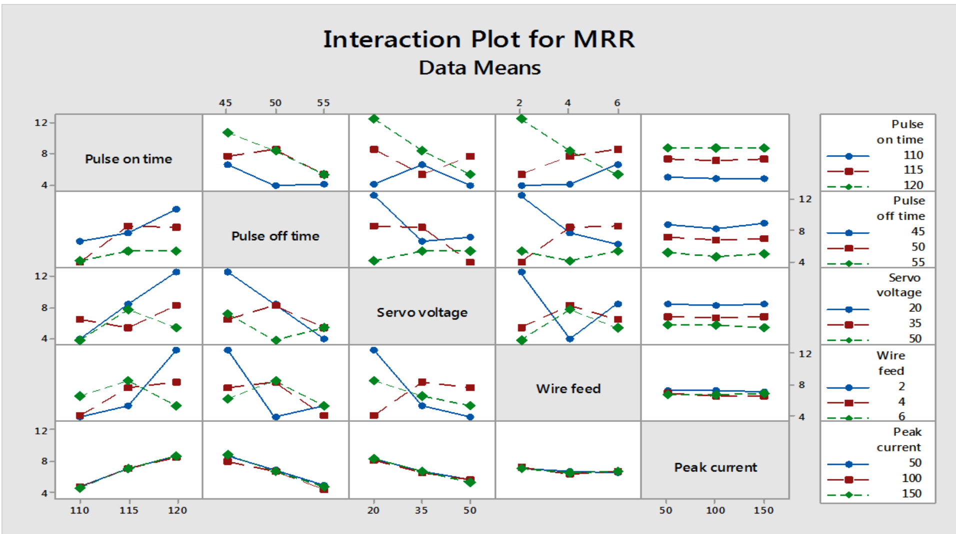

Figure 5.9: Effects of process parameters interactions on material removal rate

Table 5.7: Response table for material removal rate

Level	Pulse on time	Pulse off time	Servo voltage	Wire feed	Peak current
1	13.29	18.26	17.52	16.02	16.32
2	16.97	16.17	16.42	16.03	16.14
3	18.29	13.59	14.60	16.49	16.08
Delta	5.00	4.67	2.91	0.47	0.25
Rank	1	2	3	4	5

The response table (Table 5.7) illustrates the average of each response characteristic for each level of each factor. The table includes ranks based on delta statistics, which compare the relative magnitude of efforts for its effect on MRR. The delta statistic is the highest minus the lowest average for each factor. Minitab 17 assigns ranks based on delta values; rank 1 to highest delta value, rank 2 to the second highest and, so on. The ranks indicate the importance of each factor to the response

5. CONCLUSION

The objective of this work is to experimentally investigate and optimize the machining input parameters during wire electro-discharge machining of AISI D2 Steel. To complete this investigation; total 27 experiments are conducted according to Orthogonal Array (OA) L27 (3^5). Taguchi's design of experiments has been employed for planning experimental design. Analysis of Variance (ANOVA) has been employed to find the level of significance of each machining input variable considered response measures. Taguchi's method which is suitable for single-objective optimization was used to find to optimal combinations of input parameters for each response measures. The five machining input parameters included are pulse on time (T_{on}), Pulse off time (T_{off}), Servo voltage (SV), Peak current (I_p) and Wire feed rate (WF). The optimum mix of parameters value was found which would give in maximize the Material Removal Rate (MRR). On the basis of experimental results and their analysis, the general conclusions drawn for this work are presented below:

- The main significant factors that affect the Surface Roughness are Pulse on time and Servo Voltage
- The main significant factors that affect the Material Removal Rate are pulse on time pulse off time and Servo voltage.

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