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Modeling and analysis of micro-WEDM process of titanium alloy (Ti–6Al–4V) using response surface approach

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ABSTRACT

Micro-machining technology is effectively used in modern manufacturing industries. This paper investigates the influence of three different input parameters such as voltage, capacitance and feed rate of micro-wire electrical discharge machining (micro-WEDM) performances of material removal rate (MRR), Kerf width (KW) and surface roughness (SR) using response surface methodology with central composite design (CCD). The experiments are carried out on titanium alloy (Ti–6Al–4V). The machining characteristics are significantly influenced by the electrical and non-electrical parameters in micro-WEDM process. Analysis of variance (ANOVA) was performed to find out the significant influence of each factor. The model developed can use a genetic algorithm (GA) to determine the optimal machining conditions using multi-objective optimization technique. The optimal machining performance of material removal rate, Kerf width and surface roughness are 0.01802 mm^3/min, 101.5 μm and 0.789 μm, respectively, using this optimal machining conditions viz. voltage 100 V, capacitance 10 nF and feed rate 15 μm/s.

1. Introduction

Micro-WEDM is recognized as an effective machining technique used in a wide range of applications namely automotive, aerospace, defense, electronics, telecommunications, healthcare, environmental, industrial and consumer products of micro-feature with micro- and nano-level surface finish. Micro-WEDM is similar to macro WEDM process; it transforms electrical energy into thermal energy for eroding the material. The electrodes are immersed in dielectric liquid or flowing pressurized dielectric medium. A very small amount of work materials melt and vaporize by a series of discharge energy between tool and work piece. Debris materials are flushed out from the sparking area by the dielectric fluid. Due to the contactless process between tool and work piece, any conductive material can be machined by WEDM regardless of its hardness and toughness.

Titanium and its alloys are employed in various industries, e.g., aerospace, bio-medical, dental, automobile, due to very high strength, high hardness, low weight and corrosion resistance. The two phase (α + β) Ti–6Al–4V alloy is the most commonly used alloy compared to other titanium alloys. However, poor heat conductivity, chemical reactivity, alloying affinity with cutting tool material, low modulus of elasticity, work hardening characteristics, etc., make titanium extremely difficult to machine by conventional machining operations [1–8]. Micro-WEDM is recognized as an effective machining technique used in micro-parts machining for difficult-to-cut materials using micro-wire tool (brass, copper and zinc coated copper wire diameter range from 0.03 mm to 0.3 mm) with advantages of high machining efficiency, precision and low cost.

Kibria et al. [9] performed powder mixed micro-EDM of titanium alloy. Powder mixed deionized water can significantly enhance MRR, tool wear rate (TWR) and surface finish of micro-EDM process. Pradhan et al [10] optimized μEDM process by response surface approach while machining of Ti–6Al–4V. The observed results reveal that the pulse on time was the most influential parameter for material removal rate, overcut and taper, whereas peak current was the factor that affected tool wear rate the most. Vijay Kumar Meena et al. [11] optimized MRR, TWR and overcut for current, voltage and frequency using Taguchi based grey scale methods. Voltage has significant effects on output performance. Somashekhar et al. [12] used artificial neural network or optimizing micro-EDM input parameters for MRR. Aniza Alias et al. [13] performed experiments on titanium alloy for influence of machining feed rate in the WEDM process. The results

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show that surface roughness and MRR were increased by increasing feed rate whereas Kerf width was decreased. Yan Cherng Lin et al. [14] studied the effects of electrical discharge machining with ultrasonic vibration of titanium alloy. MRR was higher in the material produced by ultrasonic assisted EDM process. Li Mao-Sheng et al. [15] performed machining of a deep small hole in titanium alloy using polarity change. It was reported that positive polarity was superior to negative polarity. Higher MRR and lower tool wear were achieved by flushing of dielectric medium. Anil Kumar et al. [16] investigated the influence of aluminium powder mixed with electrical discharge machining process using inconel alloy. The experimental results show that the size of the particle and its concentration has significant effects in additive mixed EDM process. There are significant improvements in material removal rate, reduction of tool wear and surface finish using medium mesh size 325 aluminium additive powders. Various researchers have tried to optimize and investigate the effects of various input factors and their levels on response variables like metal removal rate (MRR), tool wear rate (TWR), and surface finish in macro-EDM and micro-EDM process [17–21]. However, limited research has been carried out on the micro-WEDM of titanium alloy, especially machining performances such as MRR, SR and Kerf width (KW), modeling and material properties. There is a need for achieving optimal machining in micro-EDM, it is important to select machining parameters carefully for economical machining operation, since machining with micro-EDM is more expensive than the conventional machining process. This paper describes the effect of various input parameters of micro-WEDM process using titanium alloy. The effects of input parameter on machining performance of micro-WEDM such as material removal rate, Kerf width, surface roughness and surface texture are presented. A multi-objective optimization technique based desirability approach and genetic algorithm are used to obtain the optimal combination of machining parameters for micro-WEDM process.

2. Materials and methods

2.1. Materials

A cylindrical zinc coated copper wire was used as the tool electrode materials with a diameter of 70 μm and work piece material was a thin metal plate of Ti–6Al–4V (ASTM Grade 5) thickness of 1 mm, length 5 mm and width 10 mm. The chemical composition of Ti–6Al–4V is presented in Table 1. Commercial grade EDM oil was used as dielectric fluid.

2.2. Response surface methodology (RSM)

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for design of experiments and optimizing process parameters [22]. RSM was used to predict the machining performance of micro-WEDM process in terms of material removal rate, Kerf width and surface roughness with input process parameters. The optimal values were obtained from the RSM based on careful planning and execution. Lin [23] evaluated the machining characteristic of micro-EDM using response surface methodology. The central composite design (CCD) is an efficient technique that could be applied to modeling of micro-WEDM in RSM. The polynomial equation formed from RSM was used to express the machining performance of the micro-WEDM process as shown in Eq. (1). In this experiment, machining performance of MRR, KW and SR were modeled in terms of voltage, capacitance and feed rate.

$$y = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} a_{ii} x_i^2 + \sum_{i<j}^{n} a_{ij} x_i x_j + \varepsilon \qquad (1)$$

where, y is the response surface, x_i and x_j are the input variables, x_i^2 and x_i and x_j are quadratic and interaction terms of input variables, respectively. The a_i, a_{ii} and a_{ij} are unknown regression coefficients. The coefficients of the response surface have been estimated by using the proposed scheme of the box and hunter in the central composite design. This model fits the second-order response surface very accurately. Replication was eliminated to finding the error term and the mean square error was estimated by replicating the center points.

2.3. Experimentation

The experimental work was conducted using DT-110 a three-axis automatic multi process integrated machining system using micro-WEDM setup with RC circuit positional accuracy of 0.1 μm. The experimental setup of micro-WEDM process is shown in Fig. 1. The different input factors and their level of micro-WEDM process are depicted in Table 2. Twenty different experimental combinations were chosen at random according to CCD in RSM. It is consists of eight star points, six center points and six axial points as shown in experimental design in Table 3. The voltage, capacitance and feed rate are considered as design variables in order to find the optimal machining performance of micro-WEDM process on titanium alloy.

In the experiments the effects of surface finish, material removal rate and Kerf width of micro-WEDM on various input parameters

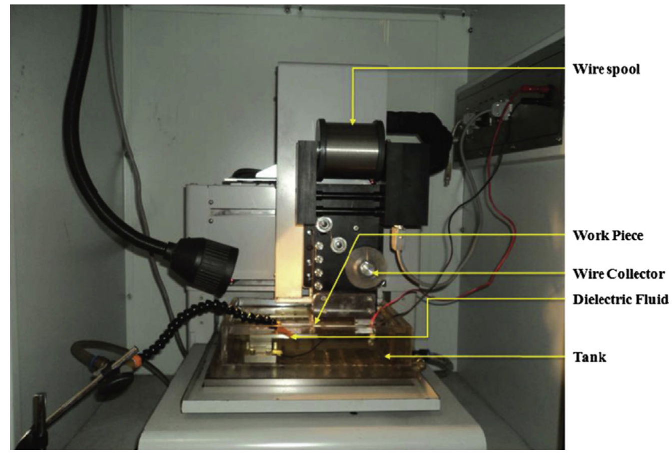

Fig. 1. Experimental setup for micro-WEDM.

Table 1
Chemical composition of Ti–6Al–4V.

Component	Al	V	Fe	O	C	N	H	Ti
Weight %	6.08	4.02	0.22	0.18	0.02	0.01	0.0053	Balance

Table 2
Input parameters and their levels of micro-WEDM process.

Variable	Symbol	Levels		
		−1	0	1
Voltage (V)	A	80	90	100
Capacitance (μF)	B	0.01	0.1	0.4
Feed rate (μm/s)	C	5	10	15