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Full Length Article

Optimization of WEDM process parameters using deep cryo-treated Inconel 718 as work material

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ABSTRACT

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. Due to the complexity and non-linearity involved in this process, good functional relationship with reasonable accuracy between performance characteristics and process parameters is difficult to obtain. To address this issue, the present study proposes artificial neural network (ANN) model to determine the relationship between input parameters and performance characteristics. Finally, the process model is optimized to obtain a best parametric combination by a new meta-heuristic approach known as bat algorithm. The results of the proposed algorithm show that the proposed method is an effective tool for simultaneous optimization of performance characteristics during taper cutting in WEDM process.

1. Introduction

In today's manufacturing scenario, nickel based super alloy such as Inconel 718 finds widespread application in aerospace, automobile and other major industries due to its high strength to weight ratio and wear resistance properties. However, these nickel based alloys are difficult to machine due to their superior mechanical properties in addition to the lower thermal conductivity. Cryogenic treatment brings some remarkable improvements in the thermal and mechanical properties through refining the microstructure of the materials. Deep cryogenic treatment refers to the treatment of the materials at very low temperature around –196 °C, which affects the entire cross section of the metal [1]. However, machining of such alloys is hardly carried out in conventional machining processes. Taper cutting operation using wire electrical discharge machining (WEDM) provides an effective solution for producing complicated and tapered profiles using any difficult-to-machine materials, super alloys and composites, especially in the aerospace and defense industries. It is basically an electro-thermal process in which material is eroded from the work piece by a series of discrete sparks between the work piece and the wire electrode (tool) separated by a thin film of dielectric fluid (de-ionized water) which is continuously fed to the machining zone to flush away the eroded particles [2]. During taper cutting operation in WEDM, the wire is subjected to deformation resulting deviations in the inclination angle of machined parts. As a result, the machined part loses its precision [3,4]. To achieve better output characteristics during taper cutting operation in WEDM process, simultaneous improvement on properties of wire electrodes and work piece materials seems to be vital.

To address this issue, Taguchi's design of experiment is used to study the effect of various process parameters on angular error, surface roughness and cutting speed during taper cutting of deep cryo-treated Inconel 718 with deep cryo-treated coated Bronco cut-W wire. Analysis of variance (ANOVA) is employed to find out the significance of the process parameters. However, the traditional Taguchi method cannot optimize multiple performance characteristics simultaneously. To overcome this limitation, a new approach known as maximum deviation theory is applied to convert multiple performance characteristics into an equivalent single performance characteristic. Traditional approaches hardly develop good functional relationship between process parameters and performance characteristics when the process behaves in a non-linear manner and involves large number of interacting parameters. To

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overcome this limitation, the relationship between process parameters and performance characteristics is developed through a back propagation neural network (BPNN) model. In order to achieve faster convergence, Levenberg–Marquardt algorithm (LMA) has been used. Bayesian regularization is also adopted due to is generalization capability to minimize error using minimal weights and thus avoids cross-validation. Finally, the process model is optimized by a new meta-heuristic approach known as bat algorithm.

2. Literature review

Many studies have been attempted in the past to improve the performance characteristics of wire electrical discharge machining (WEDM) process viz., surface roughness, cutting speed, dimensional accuracy and material removal rate using various traditional, multi-criteria decision making and evolutionary algorithm methods. However, the full potential of the process is not completely explored because of the complex and stochastic nature of the process and involvement of large number of variables. Tosun et al. [5] have presented an investigation on the effect of machining parameters on kerf and material removal rate in WEDM operations and multi-objective optimization of parameters using simulated annealing. Kuriakose and Shunmugam [6] have developed a multiple regression model to represent the relationship between input and output variables and multi-objective optimization method based on a Non-Dominated Sorting Genetic Algorithm (NSGA). Mahapatra and Patnaik [7] have established the relationship between control factors and responses like material removal rate (MRR), surface finish (SF) and kerf by means of non-linear regression analysis resulting in valid mathematical models. Finally, genetic algorithm is employed to optimize the WEDM process with multiple objectives. Sadeghi et al. [8] have applied Tabu search algorithm for optimization of material removal rate and surface roughness (SR) during wire electrical discharge machining process. Khan et al. [9] have used grey relational analysis for simultaneous optimization of surface roughness and micro hardness of the machined component of WEDM process. Jangra et al. [10] have also applied grey relational analysis with Taguchi method for simultaneous optimization of material removal rate and surface roughness in WEDM process for WC-Co composite. Mukherjee et al. [11] have applied six different non-traditional optimization algorithms such as genetic algorithm, particle swarm optimization, sheep flock algorithm, ant colony optimization, artificial bee colony and biogeography based optimization for single and multi-objective optimization of WEDM process.

Cryogenic processing of tool and work piece is also one of the major research issues for the significant improvement of machining performance of the electrical discharge machining (EDM) and WEDM process. In this direction, Kumar et al. [12] have investigated the machinability of Inconel 718 work material with ceramic powder mixed in dielectric fluid using cryogenically treated copper electrode in electrical discharge machining. Kapoor et al. [1] have investigated the effect of deep cryogenic treated brass wire electrode using Taguchi experimental design. From the analysis of variance, it is observed that wire type, pulse width, time between two pulses and wire tension are important parameters for improving material removal rate. Gill and Singh [13] have investigated the effect of deep cryogenic treatment of copper electrode on machinability of Ti 6246 alloy in electric discharge drilling. The study confirms that improved material removal rate, wear ratio (WR), tool wear rate (TWR) and precise drilled holes can be achieved with cryogenic treatment. However, most of the research works have focused on vertical cutting by WEDM. In today's manufacturing scenario, precision and die manufacturing not only requires productivity, tolerances and dimensional accuracy but also demands complicated profiles with inclined or curved surfaces. Hence, tapering process is one of the most important applications of WEDM process. The taper cutting using WEDM is first proposed by Kinoshita et al. in 1987 [14]. They have developed a linear model for wire deformation neglecting the forces produced during the process. Plaza et al. [3] have developed two models for the prediction of angular error in WEDM taper cutting and found that part thickness and taper angle are the most influencing variables. Sanchez et al. [4] have presented a numerical and empirical approach for the prediction of angular error in WEDM taper cutting. A simulation approach is adopted by Sanchez et al. [15] for analysis of angular error in wire-EDM taper cutting and verified by experimentation. Chiu et al. [16] have carried out an on-line adjustment of the axial force imposed by the machine on the wire in taper cutting. Huse and Su [17] have developed a theoretical model and concept of inclined discharge angle for material removal analysis of WEDM's tapering process and proposed a strategy including control of discharge power and wire tension for improving efficiency of the process. Kinoshita [18] has also proposed different methods to compensate the angular error in the taper cutting. However, limited studies deal with the taper cutting operation in WEDM, with least attention paid to optimize the process parameters of WEDM. The application of both cryogenic treated wire electrode and work piece is not adequately addressed in the literature. Therefore, the present study attempts to study the effect of input parameters on various performance measures using deep cryo-treated wire electrode and work piece Inconel 718 during taper cutting operation in WEDM process. Then, the process model is developed using artificial neural network model which is optimized by a recent meta-heuristic approach called bat algorithm.

3. Proposed methodology

The present work proposes an integrated approach for prediction and optimization of process parameters of WEDM process for cryo-treated wire electrode and work piece materials during taper cutting operation.

3.1. Maximum deviation theory

In the past, several multi-attribute decision making method approaches such as simple additive weight (SAW), weighted product method (WPM), technique for order of preference by similarity to ideal solution (TOPSIS), analytic hierarchy process (AHP), preference ranking organization method for enrichment of evaluations (PROMETHEE), desirability function have been adopted in converting multiple performance characteristics into a single equivalent characteristic [19–22]. However, weight assignment to various performance characteristics is quite subjective and arbitrary in nature. It severely affects the ranking of the alternatives. To avoid the embedded uncertainty and subjective assignment of weights by the experts, it is prudent to extract the accurate information from the available data. Maximum deviation theory, proposed by Wang [23], can address the issue quite effectively. The computational steps of maximum deviation theory are outlined below to compute the weight of each performance characteristic and finally composite score, which is maximized, is calculated for each alternative [24].

3.1.1. Step 1: Normalization of the evaluation matrix

The normalization process is needed to transform different scales and units among various attributes into common measurable units to allow the comparisons of different attributes. The decision matrix $[x_{ij}]$ is obtained from experimental data by treating the number of experiments as alternatives and performance characteristics as the attributes. Each element of the decision matrix $[x_{ij}]$ represents