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Experimental investigation and multi-objective optimization of wire electrical discharge machining (WEDM) of 5083 aluminum alloy

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Abstract: The experimental analysis presented aims at the selection of the most optimal machining parameter combination for wire electrical discharge machining (WEDM) of 5083 aluminum alloy. Based on the Taguchi experimental design (L9 orthogonal array) method, a series of experiments were performed by considering pulse-on time, pulse-off time, peak current and wire tension as input parameters. The surface roughness and cutting speed were considered responses. Based on the signal-to-noise (S/N) ratio, the influence of the input parameters on the responses was determined. The optimal machining parameters setting for the maximum cutting speed and minimum surface roughness were found using Taguchi methodology. Then, additive model was employed for prediction of all (3^4) possible machining combinations. Finally, a handy technology table has been reported using Pareto optimality approach.

Key words: wire electrical discharge machining (WEDM); aluminum alloy; Taguchi method; additive model; optimization; Pareto optimization

1 Introduction

Wire electrical discharge machining (WEDM) is one of the most extended non-conventional machining processes used to produce complex shapes and profiles. It is a thermoelectric process in which workpiece material is eroded by a series of discrete sparks between the workpiece and a traveling wire electrode immersed in a liquid dielectric medium. These electrical discharges melt and vaporize minute a mount of the work material, which is then ejected and flushed away by the dielectric [1]. The movement of the wire is precisely monitored by a computer-numerically controlled (CNC) system. WEDM is widely used in aerospace, automobile, medical, tool and die manufacturing industries [2]. The selection of optimum machining parameters for obtaining higher cutting speed with specified surface finish and other accuracy features is a difficult job in WEDM owing to the presence of a large number of process variables and complicated stochastic process mechanism. Hence, an elaborate study is required for optimum parameter setting to achieve the maximum process criteria yield for different classes of engineering materials. A large amount of research work has been reported for different classes of engineering materials in the area of parametric optimization of WEDM.

HEWIDY et al [3] used response surface methodology (RSM) models for correlating the inter-relationships of various WEDM machining parameters of Inconel 601. PRASAD and GOPALAKRISHNA [4] employed the RSM modeling and optimized the responses by applying non-dominated sorting genetic algorithm. KURIAKOSE and SHUNMUGAM [5] used multiple regression models and optimized the WEDM process based on non-dominated sorting genetic algorithm (NSGA) which produces the Pareto optimal set of machining parameters. SARKAR et al [6] investigated the selection of the optimum cutting condition based on the Pareto-optimality for machining γ-titanium−aluminide alloy. They also carried out the parametric optimization of WEDM to maximize the cutting speed while keeping the surface roughness within limits using the feed forward back-propagation neural network model

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[7]. RAMAKRISHNAN and KARUNAMOORTHY [8,9] optimized the WEDM responses concurrently using multi response signal-to- noise (MRSN) ratio in addition to Taguchi's parametric design approach. SPEDDING and WANG [10] presented an attempt at optimization of the process parametric combination using artificial neural networks and characterized the roughness and waviness of workpiece surface along with the cutting speed. CHIANG and CHANG [11] conducted experiments on Al_2O_3 particle reinforced material (6061 alloy) and optimized the responses based on the grey relational analysis. TOSUN et al [12] investigated the effect and optimization of machining parameters on the kerf (cutting width) and material removal rate (MRR) on AISI 4140 steel during WEDM operations. They used regression model and obtained optimum machining parameter combination by the analysis of signal-to-noise (S/N) ratio. SELVAKUMAR et al [13,14] investigated the corner accuracy aspects in wire electrical discharge machining of Monel 400 alloy and 5083 aluminium alloy, respectively. SARKAR et al [15] proposed an analytical model to measure gap force intensity and wire lag under any given machining condition.

In the present study, wire electrical discharge machining of 5083 (Tempered H112) aluminum alloy having following compositions of Mg 4.32%, Mn 0.74%, Cr 0.15%, Si 0.19%, Fe 0.27%, Cu 0.04% and the balance of Al, has been considered. Aluminium alloys have primary potential for lightweight structural application in automotive, missile and aerospace industries. Among these, 5083 aluminum alloy (5083 AA) is preferred for its reasonable strength, excellent low temperature properties (does not exhibit ductile to brittle transition and has very high toughness even at cryogenic temperatures to near absolute zero), better corrosion resistance, weldability and ability to take surface finish. It is predominantly used in marine and cryogenic industries. No or little specific machinability data are available for 5083 AA through conventional means such as turning, milling, drilling and grinding. However, TOTTEN and MACKENZIE [16] reported the machinability ratings of aluminium alloys span into five groups, with ratings of A, B, C, D and E, which are ordered in increasing order of chip length and decreasing order of surface quality. The 5083 aluminium alloy ranked D is an indicator for poor machinability. The challenges involved in machining aluminium alloys demand innovative approaches towards the design of cutting tools, especially diamond-based cutting tools. This can be totally avoided by choosing WEDM process. The WEDM is one of the attractive machining techniques to process 5083 AA to any complex shape with very high precision and accuracy.

The present work aimed at providing a customized technology table for shop floor engineers in machining aluminum alloys through WEDM process. Initial emphasis is placed on the influence of the parameters on the process criteria yield and the prediction of the responses through Taguchi-based additive models. Later, optimization of the responses has been carried out by applying Pareto-optimality approach. The optimal machining conditions proposed in this work have ample industrial applications because of the versatility of 5083 aluminium alloy.

2 Experimental design

The experiments were performed on an electra supercut 734 series 2000 CNC wire cut-EDM machine. Based on the literature survey and the trial experiments, the variables such as pulse-on time (A), pulse-off time (B), peak current (C) and wire tension (D) were considered control variables. Table 1 shows the control factors with their levels. The levels of parameters were decided based on the trial runs. There are other factors, which would have little influence on the measure of performance, are kept constant, i.e. product size (5 mm× 5 mm), temperature of the dielectric (27 °C), conductivity of the dielectric (20 Ω), dielectric pressure 0.833 MPa, work piece thickness (15 mm), pulse peak voltage setting (100 V), wire feed setting (6 m/min), servo voltage (3 V), servo feed setting (30 proportional mode), wire type (0.25 mm-diameter brass) and angle of cut (vertical).

Table 1 Control factors and their levels

Sample No.	Control factor	Symbol for coded value	Level		
			1	2	3
1	Pulse-on time (μs)	A	0.5	0.7	0.9
2	Pulse-off time (μs)	B	14	26	38
3	Peak current (A)	C	20	60	100
4	Wire tension (g)	D	420	540	660

Based on the input factors and their levels listed in Table 1, experiments were conducted by employing Taguchi's L9 orthogonal array shown in Table 2. In order to minimize the effect of random factors, each experiment was repeated thrice and the average of responses, namely cutting speed and surface roughness, are listed in Table 2. The cutting speed was recorded directly from the monitor of the machine and the surface roughness (R_a) was measured by Perthometer manufactured by Mahr, Germany.

In WEDM, the lower surface roughness and the higher cutting speed (CS) are the indication of better performance. Therefore, the lower R_a and higher CS were selected for obtaining optimum machining