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ANALYSIS AND MODELLING OF LASER-MICRO EDM-BASED HYBRID MICRO MILLING ON STAINLESS STEEL (SUS304) USING BOX BEHNKEN DESIGN

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ABSTRACT: Hybrid micro milling is drawing the attention of researchers and engineers to generate micro products with intense dimensional precision to use in discrete applications like aerospace, electronics, and optics. Laser milling is a faster machining process with a high material removal rate. It raises some problems like insufficient cutting depth, burrs, uneven edges, charred corners, and many more. On the other hand, the μEDM milling process is slower but produces a better surface finish with perfect alignment without compromising inaccuracy. This study aims to incorporate both machining advantages also to investigate the most substantial laser parameter that influences the output responses of μEDM milling time. In this hybrid micro-milling process, the stainless-steel (304) workpiece (0.5 mm thickness) was used to conduct laser micro-milling varying the laser input parameters such as scanning speed, power, pulse repetition rate, and loop. Sequentially the workpiece was shifted to the μEDM machine to continue μEDM milling with constant EDM parameters (Voltage 80 V, capacitance 1 nF, EDM milling speed 5 μm/sec) using a tungsten tool (0.5 mm thickness) and the total set of experiments (25) was run according to Box Behnken design (BBD). It was found that an increase in scanning speed (ss) factors (A) increases the μEDM milling time slightly. The laser power effect shows that a higher laser power machined slot channel consumes less μEDM milling time, which is quite significant compared to the scanning speed effect. A mathematical model was developed to correlate the laser input parameters and out responses of μEDM milling time. The optimization results reveal that power is the most significant factor affecting the μEDM milling time. Based on the Response Surface Methodology (RSM), the predicted optimized input laser parameter was scanning speed 1577.085 mm/sec, power 15.179 W, pulse repetition rate 8.42 KHz rate, and loop 5.959 nos in where the μEDM milling time would be lower 37.390 min.

KEYWORDS: *EDM, Laser, Milling*

1. INTRODUCTION

Recent advancements in micro-manufacturing enable the assembly of micro- and mesoscale structures in various engineering objects. Mechanical micro-milling, extensively researched recently, offers advantages over photolithography-based techniques [1, 2]. This process crafts small, precise components [3], used in biomedical devices, microsensors, etc., from polymer through microinjection molding [2]. Micromachining produces accurate, finely finished molds for this purpose [4]. While EDM and micro laser milling are alternatives, micro milling offers superior material removal rates and surface quality [5]. It's versatile, cost-effective, and user-friendly, making it a preferred choice [6].

Laser milling (LM) is advancing rapidly in micromanufacturing due to its ability to produce fine, precise 3D objects in various materials. In LM, a laser beam removes material layer by layer through ablation, heating it to vaporization [7]. The synergy between the laser ablation mechanism and the CNC program, derived from CAD data, is pivotal to its success. LM's advantages include machining tough materials like ceramics and graphite, no tool wear, superior surface finish, accuracy, and minute feature size [8, 9]. It excels in crafting detailed cavities or microfluidic channels. While LM offers faster material removal, its edge quality and surface roughness are inferior to micro EDM.

Micro-electrical discharge milling (micro-EDM) is a non-contact method that removes material from conductive substances through a thermal technique. This process uses electrical discharges in an insulated area between a tool electrode and a workpiece. During the discharges, a high-temperature plasma channel forms, causing localized melting and evaporation of both the workpiece and the electrode [10]. Micro EDM capability has been discussed thoroughly in [11]. Micro-EDM forces are minimal compared to mechanical methods. The process has various configurations, including micro-EDM drilling, sinking, and milling. Specifically, micro-EDM milling employs microelectrodes, which are like thin cylindrical rods, to move in set paths while rotating. Depending on the electrode diameter and discharge energy, the material is removed layer by layer, with layers as thin as 0.1 m. While micro-EDM offers superior surface finish and accuracy, its machining time is longer than laser machining.

A hybrid process has been introduced to address the shortcomings of laser and micro EDM machining. This method mitigates environmental impacts, enhances manufacturing efficiency, and benefits components with intricate geometry. While µEDM milling is inherently slower, following laser milling, it proves faster than standalone EDM milling. The performance of µEDM is influenced by laser parameters, especially in 1-D drilling [12]. A dual-stage artificial neural network model was developed to refine the parameters of this hybrid micromachining [13]. Several optimization techniques, like the Taguchi method, ANOVA, RSM, and GRA, are utilized to fine-tune the process. The objective is to pinpoint the optimal parameters that influence outcomes, such as tool wear and surface roughness [14]. Rajesh [14] employed RSM for multi-response optimization in turning, focusing on parameters like spindle speed and feed rate. Similarly, Bhuvnesh Bhardwaj et al. [15] utilized RSM for carbide insert end milling of AISI1019 steel, deriving empirical models for surface roughness. Emel Kuram and Babur Ozcelik [16] used the Taguchi method to study micro-milling effects on AISI 304 steel, considering factors like spindle speed and feed rate. In multi-response optimization via RSM, each outcome receives equal weightage.

Laser-assisted milling is well-researched, with some studies exploring macro-scale laser-assisted machining of ceramics [1]. However, research on laser-EDM based hybrid micro milling remains sparse. This paper offers an experimental study and an RSM-based model analysis, focusing on the interplay between laser parameters and µEDM milling time outputs. The optimization and contributions of the model are detailed.

2. MATERIALS AND METHODS

This study was done based on the experimental investigation to determine the outcome of laser parameters and how they affect the output execution of µEDM milling operation and a mathematical model was developed. In this research, the workpiece material used was stainless steel (SUS 304) with dimensions of 22.5 mm x 22.5 mm x 0.5 mm. Stainless steel is widely used in various applications due to its corrosion resistance. As part of the laser-µEDM based micro milling process at first the laser milling was carried out on a fiber laser system as shown in Fig. 1. Then, the workpiece was transferred to the (Fig. 2) to carry out the µEDM process for fine finishing. The machined slots were characterized using optical instrumentation.

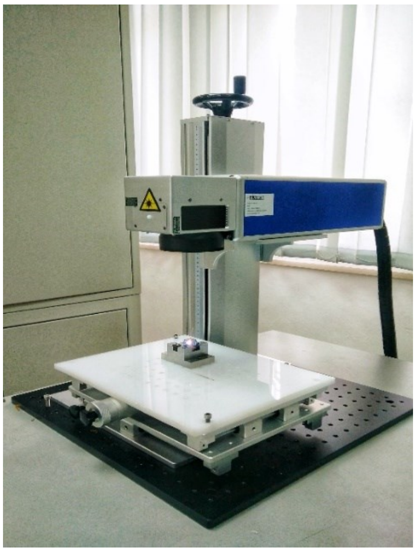

Fig. 1. Laser setup [12]

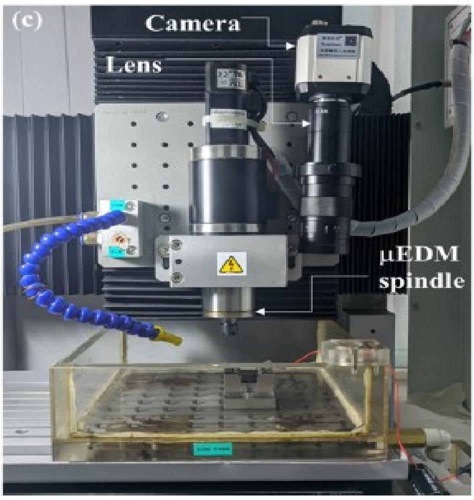

Fig. 2. µEDM setup.

3. RESULTS AND DISCUSSIONS

In this research, a prepatterned laser slot was machined using a variety of laser parameters and then finally, the slot was fine finished with constant total depth by the EDM process. Here we monitored the EDM time to see how laser parameters affected the EDM finishing time.

3.1 Dimensional Surface plot for µEDM milling time.

Here, experimental data were used to develop an empirical model (response surface method) of the EDM finishing time as a function of laser parameters. Fig. 3 shows the effect of laser power and scanning speed on the time required by the EDM process to carry out the fine finishing process. It can be seen from Fig. 3 that if higher power with lower scanning speed is used for the pilot machining process by laser, then the finishing time by the EDM process becomes shorter as most of the material is removed by the laser process due to the use of higher laser power with slower scanning speed.

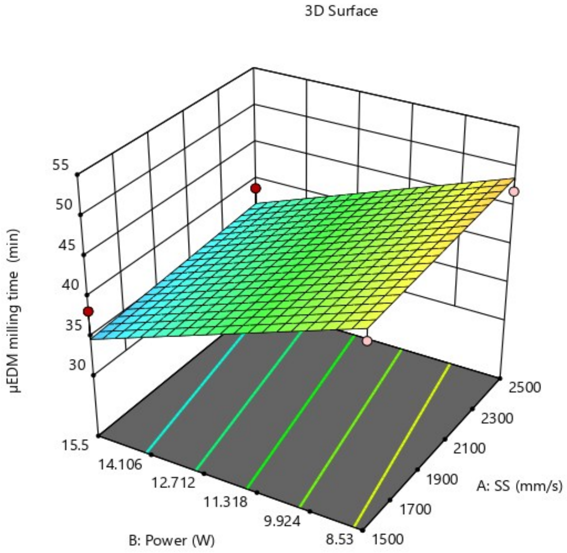

Fig. 3. Shows how EDM finishing time varies with laser machining parameters (laser power and laser scanning speed).

Fig.4, on the other hand, shows that pulse repetition rate does not have any significant effect on the final finishing time by the EDM process and loop count has an inverse effect on the machining time by the EDM process.

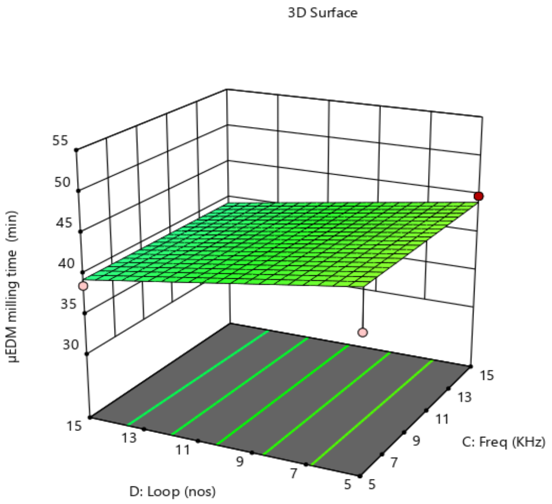

Fig.4. Shows how EDM finishing time is varied with laser machining parameters (loop count and pulse frequency).

4. CONCLUSIONS

In this study, the experimental table was designed using the Box-Behnken method, and ANOVA was employed for analysis. The µEDM milling time served as the response, with laser input parameters being the scanning speed, power, pulse repetition rate, and loops. It was observed that the laser power had the most significant impact on the µEDM milling time output responses.

The predicted optimal laser input parameters were a scanning speed of 1577.085 mm/sec, power of 15.179 W, pulse repetition rate of 8.42 kHz, and 5.959 loops, reducing µEDM milling time of 37.390 minutes.

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