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Full Length Article

Experimental investigation on low-frequency vibration assisted micro-WEDM of Inconel 718

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ABSTRACT

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. It was observed that in micro-WEDM, the capacitance is the most significant factor affecting both MRR and kerf width. It was witnessed that the low-frequency workpiece vibration improves the performance of micro-WEDM by improving the MRR due to enhanced flushing conditions and reduced electrode-workpiece adhesion.

1. Introduction

The Nickel-based superalloys find widespread application in aerospace, automobile, medical, and chemical industries owing to their excellent resistivity to corrosion and oxidation, high creep-rupture strength, and fatigue endurance limit. Among Nickel-based superalloys, Inconel 718 is largely used in the aerospace segment for fabricating of gas turbine engine components such as turbine disks, blades, combustors and casings, nuclear power plant components such as reactor and pump, spacecraft structural components, medical devices, food processing equipment, extrusion dies and containers, casting dies, hot work tools and dies, etc. [1,2]. However, Inconel-718 pose a substantial difficulties during traditional machining because of its small thermal conductivity, high work hardening characteristic, hot-hardness, chemical affection to tool material [1,3–5]. Hence, non-traditional machining processes are favored over traditional processes while machining of Inconel 718.

Wire electrical discharge machining (WEDM) is one of the important and widely used non-traditional, thermoelectric processes in manufacturing industries owing to its capability to machine intricate and free forms with very thin wires [6,7]. The physical behavior and working principle of WEDM process is well defined in the literature [8–10]. In last decade, micro-WEDM, which is a variant of WEDM, has evolved as a competent technique for machining and fabrication of micro-features in such difficult-to-cut materials regardless of their hardness. In micro-WEDM, small pulse energies are predominant, and constantly moving wire (diameter 25–150 µm) are required as tool-electrode. With benefits such as high machining efficiency, precision, and low cost, micro-WEDM gets upper-hand over the other micro-machining processes and has been extensively used in aerospace and nuclear space industry for machining of difficult-to-cut materials [11,12].

Numerous research studies have been reported on machining of conductive materials including metals, composites, ceramics, and metal matrix composites using WEDM over last two decades. In general, the machining performance of WEDM is mainly influenced by a combination of electrical, mechanical, physical, and geometrical properties of the wire electrode, properties of the workpiece material, mechanical machine concept, machine intelligence, pulse generator technology, and dielectric flushing method. Mahapatra and Patnaik [8] have investigated the effects of various parameters including discharge current, pulse duration, pulse frequency, wire speeds, wire tension, and dielectric flow rate on metal removal rate (MRR), surface finish (SF) and cutting width (kerf). They used a genetic algorithm for multi-objective optimization of WEDM.

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Authors of [13] used non-dominated sorting genetic algorithm-II (NSGA-II) to determine optimum process parameters in WEDM of AISI D3 for cutting rate and surface roughness. Kumar and Agrawal [14] optimized WEDM process parameter while machining high-speed steel with zinc-coated wire. They applied NSGA-II optimization technique for multi-objective optimization of cutting rate and surface finish.

The machining of titanium alloys, composites using WEDM has also been reported in the literature. Kuriakose et al. [15] machined Ti-6Al-4V titanium alloy using zinc-coated brass wire and applied machine learning-based data mining approach to study the effect of various process parameters on the cutting speed and surface finish. Machining and optimization of γ-titanium aluminide alloy have been reported in [16]. They used constrained optimization and Pareto optimization algorithm for parametric optimization of WEDM for the cutting speed, surface finish, and dimensional deviation. Manna and Bhattacharya [17] machined aluminium-reinforced silicon carbide metal matrix composite using WEDM and determined optimum machining condition by Gauss elimination dual response method. Patil and Brahmankar [18] examined the effect of WEDM parameters on surface finish, cutting speed, and kerf width using Taguchi's method while machining alumina particulate reinforced aluminum matrix composites (Al/Al2O3p) with coated brass wire material. Bobbili et al. [19] presented machining of armor materials such as aluminum alloy 7017 and rolled homogeneous armor (RHA) steel using WEDM. They further extended this work presenting multi-objective optimization of process parameters [20].

Recently, various studies have been reported [21–23] explaining the effect of different process parameters on the response measures of micro-WEDM. Han et al. [21] established a 3-D temperature and stress distribution in micro-WEDM numerically. Das and Joshi [22] have developed a mathematical model for micro-WEDM considering plasma features, moving heat source characteristics, multi-spark phenomenon, and wire vibration effect to predict the cathode erosion rate. The effects of RC-circuit process parameters on micro-WEDM performance were explained by [23]. They established mathematical models to predict the performance measures and confirmed experimentally.

Very few studies are reported on machining of Nickel-based superalloys like Inconel 718 using WEDM. The superior properties of Inconel 718, like high resistivity to corrosion and high temperature resistant, makes it competent for elevated temperature application [5,24]. Goswami and Kumar [25] investigated and optimized the input process parameters of WEDM while machining Nimonic 80A superalloy. Hewidy et al. [26] established a mathematical relationship between WEDM process parameter and performance measure viz. MRR, wear ratio, and surface roughness based on the response surface methodology in WEDM of Inconel 601 using copper wire. Ramakrishnan and Karunamoorthy [27,28] predicted the performance of WEDM of Inconel 718 using the artificial neural network. Further, they optimized MRR and surface roughness using multi-response optimization. Agrawal et al. [2] presented empirical modeling of WEDM process parameters for Inconel 718 using response surface methodology (RSM). They optimized the process performance using desirability function approach. Recently, Nayak and Mahapatra [29] presented optimization of process parameters of WEDM during machining of cryo-treated Inconel 718. It is also noticed that no study is available which reports the micro-WEDM of Inconel 718 superalloy.

The application of low-frequency workpiece vibration in micro-EDM processes has resulted in improved machining performance due to enhanced flushing conditions and reduced unstable machining conditions [30–33]. Jahan et al. [30,31] evaluated low-frequency vibration assisted µ-ED drilling of tungsten carbide and claimed that low-frequency vibration has a considerable effect on both the machining characteristics and micro-hole accuracy parameters. Recently, Lee et al. [32] concluded that low-frequency workpiece vibration (10–70 Hz) during the µ-ED drilling results in reduced machining time by 70% related to that of machining without vibration at non-rotating electrode condition. The applications of µ-WEDM are still limited owing to low machining rate of the process. No study is reported on the application of low-frequency workpiece vibration in the µ-WEDM process. Therefore, an attempt is made to improve the performance of µ-WEDM with a low-frequency workpiece vibration assistance. The gap voltage, capacitance, wire feed rate, and vibration frequency are selected as input parameters while MRR and kerf are chosen as performance measures.

2. Materials and methods

2.1. Materials

The workpiece specimen of size 27 mm × 10 mm × 2.5 mm is prepared out of commercially available Inconel 718 by using a high-speed diamond cutter (Isomet 4000 Buehler). Semiautomatic polishing machine (MetaServ® 250 Buehler) is used for polishing and grounding of workpiece specimen. The composition of the prepared Inconel 718 specimen was determined using an optical spectrometer (LECO GDS500A) which was found to be 54.4% Ni, 0.04% C, 0.084% Si, 0.06% Mn, 0.001% P, 18.8% Cr, 8.84% Fe, 13.3% Mo, 0.085 V, 2.78% Nb, 0.259%W, 0.259 Co, 0.814% Ti, 0.194% Al, 0.078% Zr. A cylindrical zinc coated brass wire (diameter 70 µm) was used as a tool electrode. The commercial "TOTAL DIEL7500IN" dielectric fluid was used as dielectric oil due to its high flash point, and high dielectric strength.

2.2. Experimentation

Mikrotools DT110 integrated multi-process micromachining tool working on the RC-pulse generator with a positional accuracy of 0.1 µm was used to perform the micro-WEDM experiments. The positive workpiece polarity was chosen as it leads to more material removal from the workpiece as compared to negative polarity electrode. The schematic representation of vibration-assisted micro-WEDM setup is shown in Fig. 1. The photograph of the experimental setup is shown in Fig. 2. The vibration device provided along with the machine tool works on the electromagnetic actuation principle and is capable of generating low-frequency vibration within 0–100 Hz. A power transistor switch supplies the periodic power supply to the electromagnet, and the control

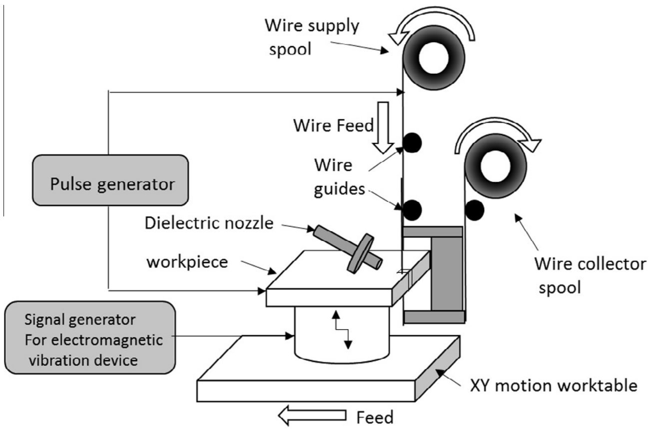

Fig. 1. Schematic diagram of vibration assisted micro-WEDM.