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Fabrication of microcylinder using a tubular electrode in magnetic levitation based μ-EDM

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Abstract

The current work deals with the fabrication of a micro-cylinder (micropillar) using a newly developed maglev electrical discharge machining process (maglev EDM). The interelectrode gap has been maintained by balancing the two magnetic repulsive forces i.e., electromagnetic repulsive force (F_{em}) and restoring force (F_{rs}). Moreover, the use of an actuator arm levitates the tool stably and precisely during discharge. The fabricated microcylinder was well defined in shape and size which was confirmed by the high-definition microscopic images. The measured height and diameter of the microcylinder were approximately 45-50 μm and 1050-1100 μm respectively. The duplex stainless steel (grade 2205) and tubular brass electrodes were the workpiece and tool material and machining was carried out in a deionized water medium. The measured discharge voltage and discharge current were 7.5-8V and 800-900 mA during the machining process. The voltage and current curve (V-I) indicates that the machining process is stable. The fabrication of a well-defined microcylinder confirms its feasibility for machining through maglev EDM.

Keywords: Maglev EDM, Actuator arm, Micro cylinder, Voltage-current curve, microscopic images.

1. Introduction

Micro electrical discharge machining (μ-EDM) is a thermoelectric machining process in which material is removed due to the thermal impact of electrical discharge [1]. In this process, a high-temperature plasma channel is created between the two electrodes in a micro-confined gap (spark gap) by applying some voltage potential. The applied voltage potential breaks the dielectric strength of the dielectric to creates a huge amount of heat which removes the materials from both the electrodes via melting and evaporation [2]. The major advantage of this machining process is it is non-contact type and free from any types of mechanical stress and vibration [3]. It can be applied to any conductive material regardless of its physical property such as hardness and toughness [4]. Moreover, the process has the unique capability to fabricates any complex shape and features.

In micro EDM, as the complete machining phenomenon is happening in a very small gap (≤10μm) hence monitoring the gap condition is very essential. The servo control mechanism is generally used to control the interelectrode gap. Moreover, the servo control mechanism responded well corresponds to the gap condition to avoid any unwanted signal such as arcing and short-circuiting. Normally, a lead screw, belt drive, and gear-based system are used to design the servo control mechanism. However, this type of servo control drives posing the issue of mass inertia, backlash, and windup losses which slow down the response frequency of the system. The slow response frequency of the servo system further leads to a short-circuiting and arcing-like phenomenon which decreases the process efficiency, stability, and accuracy of the machined product. Moreover, the currently designed servo gap controller uses complex algorithms such as fuzzy logic control [5], artificial neural network [6], proportional integral derivative (PID) [7], and genetic algorithm [8], etc. This type of servo gap controller has certain limitations in terms of speed, feed, and response, etc.

Magnetic levitation is one of the feasible solutions for controlling the interelectrode gap. The designed servo system based on this principle is free from the above-mentioned issues. The response frequency of this type of positioning system is also high compared to the conventional one. Moreover, the quick response of this type of system improves the machining stability and accuracy. Guo et al. [9] designed a magnetic suspension-based spindle for improving the response frequency of the micro-EDM system. They achieved the positioning accuracy of 2 μm and 5 μm in radial and axial directions. Furthermore, the system attained the response frequency of 150 Hz for the stroke length of 1.3 mm in the Z direction. Feng et al. [10] fabricated the microholes on Inconel 718 using the magnetically levitated spindle. They found improvement in MRR by 23% with a very low tool wear rate (43% less) compared to the conventional EDM system. The recast layer was also found less at the inlet and outlet of the micro-holes which signifies the machining process is highly stable and efficient. He et al. [11] designed a 5-degree of freedom local actuator arm for high-speed micro EDM processing using the magnetic levitation principle. The spindle was levitated using a magnetic bearing and some magnetic coupling system. The actuator arm achieved the positioning resolution of the submicron level with a high positioning response frequency (greater than 200Hz). It was also found that the system had got enough stability for fabricating the micro-holes with a fast response time. A similar type of actuator arm is reported by Zhang et al. [12] for improving the micro EDM processing speed. The local actuator arm attained the submicron and microradian positioning resolution for the stroke length of 2 mm in the axial direction with a response frequency of 100 Hz.

Current work tested the feasibility of newly developed maglev EDM for fabricating the microcylinder. The frequency response of the actuator arm was high compared to the conventional EDM. Here, the two magnetic repulsive force has been made balanced by magnetic levitation principle. The equilibrium state of the two magnetic forces (F_{em}=F_{rs}) facilitates good control over the interelectrode gap. Later on, the shape and size of the fabricated microcylinder were measured and analyzed by image processing software called Image J. The surface morphology and topography were analyzed by high-definition microscopic images. The study of voltage and current (V-I) discharge characteristic curve was also done which indicates that the machining process is stable enough to fabricate the microcylinder.

2. Materials and methods

2.1. Maglev EDM

The working principle of maglev EDM is based on the concept of magnetic levitation. Here, the servo stabilized gap control mechanism has been developed by balancing the two magnetic repulsive forces i.e., electromagnetic repulsive force (F_{em}) and restoring force (F_{rs}). The electromagnetic repulsive force is acting between the electromagnet (EM) and movable permanent magnet (PM1) while the restoring force is acting between the fixed permanent magnet (PM2) and movable permanent magnet (PM1). The arrangement of different magnets for controlling the interelectrode gap and the actual setup is shown in fig. 1. The tool electrode is attached with the movable permanent magnet (PM1) as well as the actuator arm. Above the movable permanent magnet (PM1), an electromagnet has been fixed and below this permanent magnet (PM2) is fixed with a workpiece electrode. A DC power supply is connected to the tool and workpiece (straight polarity) and parallelly with the electromagnet. The arrangement was made in such a way that the movement of the tool electrode towards the workpiece decreases the interelectrode gap. The reduction in the interelectrode gap decreases the voltage potential of the electromagnet and hence reduces the magnetic field strength of the electromagnet (F_{em}). As magnetic repulsive force decreases, the restoring force (F_{rs}) magnitude starts increasing. A situation comes where electromagnetic repulsive force will be equals to the restoring force (F_{em}=F_{rs}). In this situation, the discharge happens and materials are removed. The occurrence of discharge reduces the magnetic field strength of the electromagnet and the tool will be retracted back to the initial gap condition. The cycle repeats continuously and machining occurs through electrical discharge.

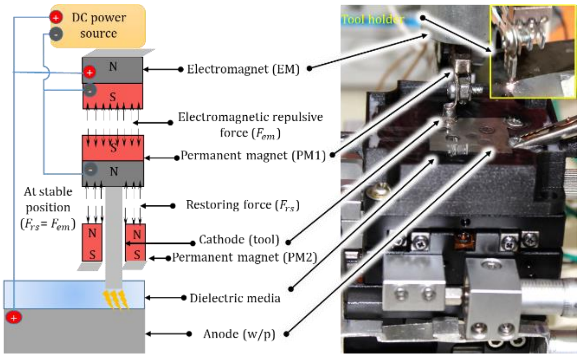


Fig.1 Arrangement of various magnets for controlling the interelectrode gap and the actual figure of the maglev EDM system.

2.2. Materials and machining environment

A duplex stainless steel of grade 2205 (Supplier: Special Metals, Mumbai) was used as the work material. The material is preferably chosen due to its remarkable properties such as high oxidation strength and temperature resistance. Moreover, it posing research challenges in terms of machinability and widely utilized material for industrial application. Fig. 2(a) indicates the fabricated microcylinder on the processed material DSS.

A tubular brass electrode (Supplier: Tech CNC solutions, Bengaluru) with an orifice was selected as the tool electrode material. The inner diameter (ID) of the orifice was 1.2 mm while the outer diameter (OD) was 3 mm. Fig. 2(b) indicates the tubular brass tool. The availability of orifice in the tool electrode offers the condition for the fabrication of microcylinder during machining. The commercial-grade deionized water has been used as the dielectric fluid. Table 1 represents the details of selected materials and applied experimental conditions.

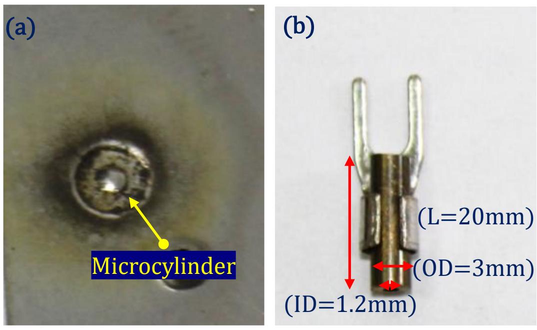


Fig. 2 (a) The fabricated microcylinder on duplex stainless steel (grade 2205) (b) tubular brass tool electrode.

Table 1 Materials and applied experimental condition

a. Material selected	
Workpiece	Duplex stainless steel (grade 2205)
Tool	Tubular brass electrode (OD=3 mm), (ID=1.2 mm)
Dielectric media	Deionized water
Polarity	Straight
b. Machining condition	
Open circuit voltage	12V
Set peak current	1.0A
Discharge voltage	7.5-8V
Discharge current	800-900mA
Duty factor	0.9564
Machining time	10 minutes

3. Results and discussion

After experimenting, the sample was cleaned with ethanol followed by distilled water to remove dirt and impurities attached to the surface.

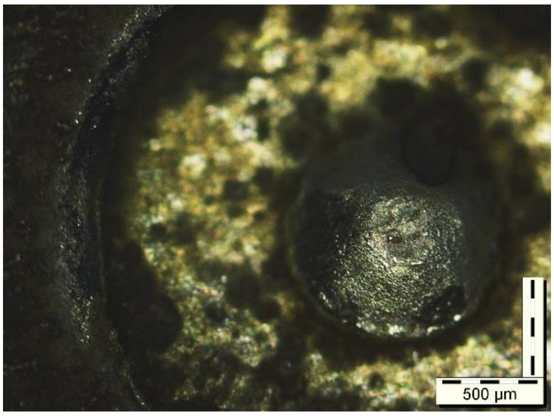
3.1. Micro cylinder fabrication

Fabricating micro-size features through

conventional technique is a challenging task due to the limitation of the machining process in terms of vibration, mechanical stress, and other mechanical disturbance. Micro-EDM is a non-contact type machining process hence its principle is applied here for fabricating the microcylinder. A voltage potential of 12V is applied by fixing the peak current of 1A. It was found that the discharge happens at a discharge voltage of 7.5-8V while the discharge current was 800-900mA. A continuous spark was found between the two electrodes and the material was removed in the form of tiny debris. The machining time was fixed for 10 minutes. The continuous discharge creates a negative impression of the tool on the workpiece. Later on, the material removal rate and tool wear rate were estimated by the weight reduction method. It was found that the MRR was approximately 70-80 µg/min while the TWR was 4-5 µg/min.

After machining, the surface morphology/topography was analyzed via a high-definition microscope (Olympus-BX51M). The image was taken at 200µm and 500 µm scales using 5X and 10X magnification. The field of view (FOV) for 5X and 10X were 4.4mm and 2.2mm, depth of focus 98 µm and 18 µm, and spatial resolution 3.36 and 1.34 were selected respectively. The microscopic image of the fabricated microcylinder and edge surface is shown in fig. 3. The analysis of the image indicates that the fabricated microcylinder is well defined in shape. Some micro debris particles were attached with the machined surface which may come due to the insufficient flushing pressure inside the gap. Some recast layer formation was also found near the edge of the surface which comes due to the re-solidification of the removed particles. Very few black spots were found over the machined surface which may indicate some arcing pulses. However, most of the discharge pulses were stable over the effective pulse of time. Later on, the height and diameter of the fabricated microcylinder were also measured using image processing software called Image J. The results indicate that the height of the micro cylinder was approximately 45-50µm while the average diameter was 1050-1100 µm.

(a) fabricated microcylinder



(b) edge surface

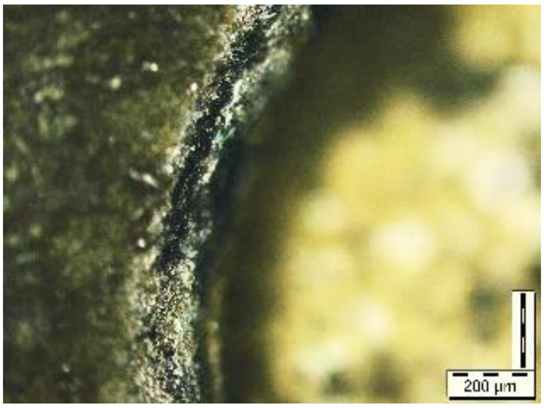
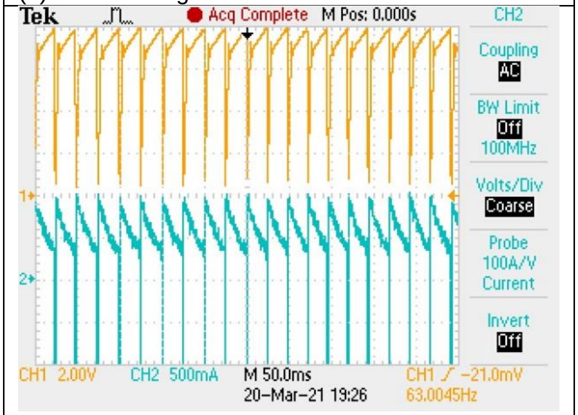


Fig. 3 (a) fabricated microcylinder (b) edge surface near the microcylinder.

3.2. Voltage current (V-I) curve

The current and voltage waveform during machining was captured using differential type current (Hantek, 65A, AC/DC) and voltage probe (TPP0201, Tektronix) in digital storage oscilloscope (Tektronix, TDS2012C, 2-channel, 100MHz bandwidth). Fig. 4(a) indicates that most of the voltage-current waveforms are stable. This also indicates that the machining process is stable enough to fabricate the microcylinder. Fig. 4(b) was used to check the pulse width of the current-voltage signal and it was found that the pulse widths were uniform and identical. A negligible amount of arcing and short-circuiting were found which indicates that the mechanism is controlling the interelectrode gap precisely. Later on, the electrical information such as discharge voltage (7.5-8V), discharge current (800-900mA), and duty factor (0.9564) was used to calculate the discharge energy power which was found approx. 6.5-7.00 watt.

(a) stable voltage-current waveform



(b) uniform pulse width signal

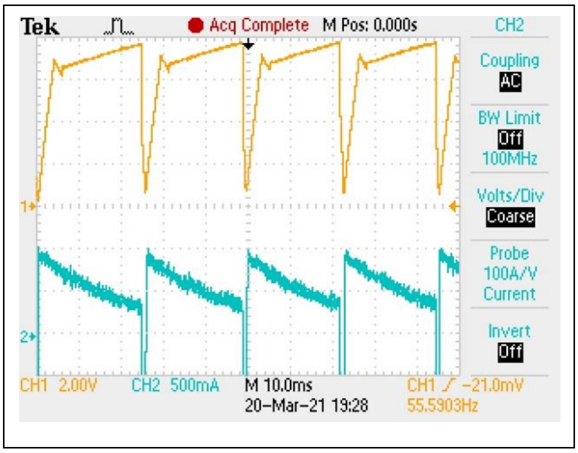


Fig. 4 Real-time voltage-current curve during fabrication of microcylinder through maglev EDM (a) stable voltage-current (b) uniform pulse width.

4. Conclusions

The following conclusions can be drawn from the above study: -

- The developed maglev EDM is feasible enough to fabricate the microcylinder of height 45-50 µm and diameter 1050-1100 µm.
- The actuator arm improves the machining condition by action of quick jumping (oscillation) and self-retraction.
- The absence of unwanted signals such as arcing and short-circuiting in the voltage-current signal indicates that the process is stable.

Acknowledgments

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