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Micro electrical discharge machining in nitrogen plasma jet

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A B S T R A C T

Dielectric, such as kerosene-based oil, deionized water or air, is an essential part of electrical discharge machining (EDM). It directly influences machining performance of the EDM process. While there is large tool electrode wear during machining in liquid dielectric, micro EDM in gas dielectric exhibits almost no tool electrode wear. However, small discharge energy, low dynamic viscosity and low debris concentration of micro EDM in gas creates narrow discharge gap, causing frequent occurrence of abnormal discharge. In this paper, nitrogen plasma jet (NPJ) is used as a dielectric to increase the discharge gap of micro EDM in gas. The machining characteristics of micro EDM in NPJ are investigated and compared with those in other dielectrics. It was found that the discharge distance, machining efficiency and surface quality are significantly improved in NPJ, compared to those in gas under the same conditions. The coaxial high-velocity air jet is helpful to reduce short circuits. Experimental results reveal that NPJ is a viable dielectric in micro EDM.

1. Introduction

Micro EDM has the ability to generate micro features in any electrically conductive material regardless of its hardness and strength. It is used to drill micro holes in diesel engine fuel injection nozzle and to generate micro molds [1]. Micro EDM can drill micro holes with diameters of 5 μm [2]. Complex 3D micro cavities have been machined using simple shaped electrodes [3,4].

Dielectric is an essential part of EDM process. In the case of liquid dielectric, (e.g., kerosene-based oil, deionized water (DIW) or mist), explosion occurs at the end of an electrical discharge due to the quick vaporization of liquid. This causes molten material to be blown into the liquid dielectric, resulting in material removal and tool electrode wear. The molten material is solidified into debris particles, and then flushed away by the liquid dielectric. In the case of gas as dielectric, molten material is directly blown out of the discharge point by compressed gas from the pipe electrode.

Properties of dielectric including dielectric strength, thermal conductivity, heat capacity and dynamic viscosity, influence the machining characteristics of EDM [5]. Usually, kerosene-based oil is used in die-sinking EDM. The discharge gap is small and machining accuracy is high. Disadvantages of kerosene-based oil include air pollution and potential fire hazard. In addition, the occurrence of abnormal discharges increases due to the increase of debris as carbon is decomposed from oil during machining. Disadvantages in DIW as dielectric differ from kerosene-based oil. When discharges occur, the polluted water has to be removed from the working zone immediately. Otherwise, electrical chemical machining occurs. In industrial application, DIW is widely used in wire EDM because debris and polluted water can be easily flushed away along the straight wire electrode. In the 1990s, gas was proposed as a dielectric in EDM. While large tool electrode wear exists in EDM using liquid dielectric, tool electrode wear ratio (TWR) is close to zero when gas dielectric is used. Molten or vaporized material during discharges in gas is attached to the tool electrode surface to protect the tool electrode from wear [6]. In some cases, material removal rate (MRR) in gas is higher than that in oil under same machining conditions [7]. The disadvantage of EDM in gas is the narrow discharge gap, which cause frequent short circuits [8]. The rotation of electrode and the planetary movement of electrode are used to improve the unstable machining process of EDM in gas [6].

TWR is large during micro EDM in liquid dielectric. In 3D micro EDM, tool electrode diameter is usually less than 100 μm. Tool electrode wear has to be compensated to generate accurate micro cavities. Such tiny pipe electrode is unavailable on the market. To utilize the advantage of near zero TWR in gas, dielectric has to be provided from outside of the tool electrode. The discharge distance in micro EDM is several micrometers long due to small electrical discharge energy. The discharge distance has to be enlarged to use compressed gas to remove molten material from the narrow discharge gap, while avoiding short circuits. In this study, nitrogen plasma jet (NPJ) is proposed as a dielectric. The corresponding experimental equipment is developed. The machining characteristics of micro EDM in NPJ, such as the discharge

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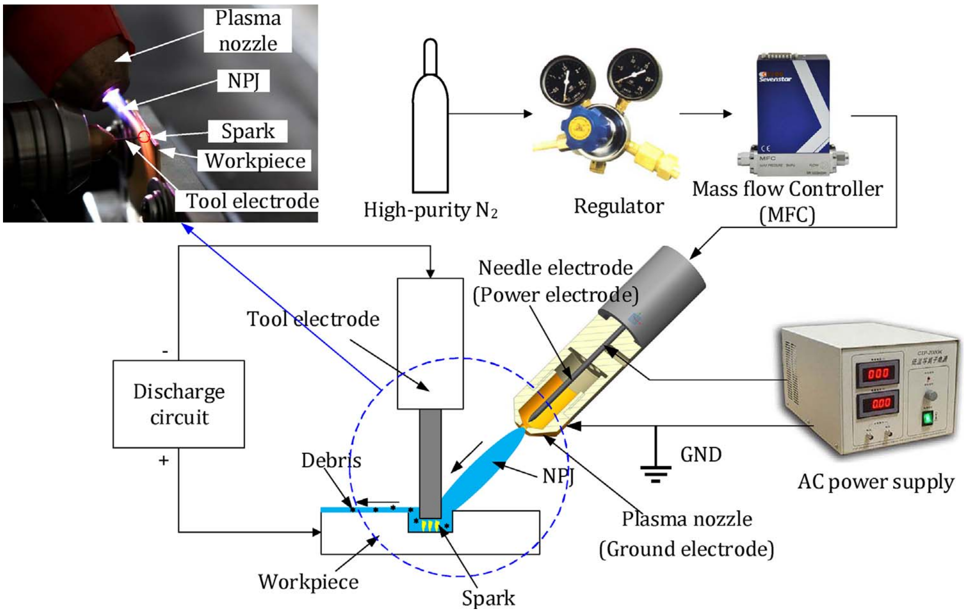

Fig. 1. Structure of micro EDM in NPJ.

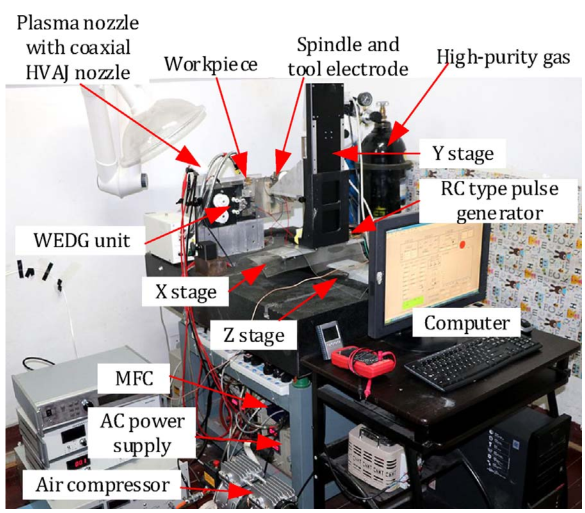

Fig. 2. Experimental equipment.

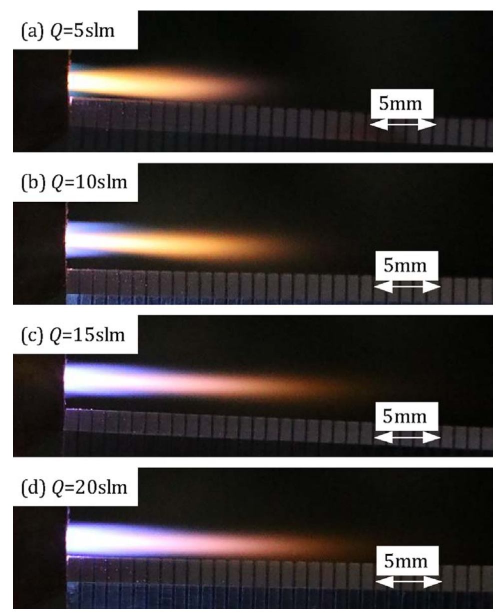

Fig. 3. NPJ under different flow rates.

distance, MRR, TWR, surface roughness and discharge gap, are investigated and compared with those in other dielectrics. Experimental results are analyzed and discussed.

2. Principle of micro EDM in nitrogen plasma jet

A discharge gap in clean dielectric is smaller than that with debris due to the bridge function of debris in the discharge gap [9]. At the same time, large tool electrode wear in liquid dielectric increases the discharge gap. The discharge gap of EDM in gas is less than that in liquid dielectric because debris is directly blown away from the gap without increasing the electrical conductivity of gap [8]. The difficulty of removing molten material from the narrow discharge gap results in frequent occurrence of abnormal discharges. To enable the process of micro EDM in gas stable, it is necessary to enlarge the discharge gap.

As shown in Fig. 1, a high velocity NPJ replaces DIW or oil as the dielectric in micro EDM, which cools down the discharge area. NPJ blows away molten or evaporated workpiece material from the discharge gap and solidifies debris. During electrical discharge off-time, the high velocity NPJ helps the discharge gap to its initial conditions. While tool electrodes used in EDM in gas are mostly pipe tool electrodes with internal supplying mode, all tool electrodes used in this paper are cylindrical solid rods with external blowing mode.

In this study, NPJ is generated by using needle-cylinder type corona discharge with AC power supply in pure nitrogen gas, as shown in Fig. 1. Corona discharge is a weak luminous discharge, which usually occurs near where the non-uniform electric field is sufficiently large at atmospheric pressure, such as sharp needles, sharp edges, sharp points or small diameter wires [10]. When a corona discharge is initiated, the current is quite low and the voltage has no significant change [11]. Ionization takes place only locally, and the breakdown circuit is closed by displacement current in the initial stages of the corona discharge [10,11]. By increasing the discharge voltage, the gap between power electrode and ground electrode breaks down and the corona discharge transfers into the spark discharge [10]. Temperatures of this kind of plasma jet can be reduced to near room temperature values, causing no thermal damage to the workpiece material [12]. NPJ is composed of ions, free electrons, excited states atoms, molecules, free radicals and so on [12]. These particles may increase electrical conductivity of the discharge gap. Hence, the discharge gap may be enlarged, which may