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INFLUENCE OF PULSE DURATION ON SURFACE ROUGHNESS IN ASSISTING ELECTRODE ELECTRIC DISCHARGE MACHINING

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Abstract: *Electrical discharge machining (EDM) is an unconventional machining process that can machine all electrically conductive materials, regardless of their physical and metallurgical properties. Due to the efficiency of machining modern engineering materials, existing EDM methods are constantly being researched and improved or developed. This paper deals with an innovative method that enables EDM machining of non-conductive ceramic material, named Assisting Electrode Electrical Discharge Machining (AEEDM). It combines electrical discharge machining with a hybrid assisting electrode. The aim of the study is to find the influence of pulse duration on surface roughness. For the set machining conditions, it was found that the surface roughness was increased by increasing the pulse duration. It should be emphasized that the supporting electrode method is used only in the electroerosion of electrically non-conductive materials.*
Key words: *EDM, hybrid assisting electrode, pulse duration, surface roughness*

Uticaj dužine trajanja impulsa na hrapavost obrađene površine pri elektroerozivnoj obradi sa pomoćnom elektrodom. *Elektrorrozivna obrada (EDM) je nekonvencionalan postupak obrade koji može da obrađuje sve elektro provodljive materijale, bez obzira na njihova fizička i metalurška svojstva. U cilju dalje efikasnosti elektroerozivne obrade savremenih inženjerskih materijala permanentno se istražuju i unapređuju postojeći ili razvijaju inovacioni EDM procesi. Ovaj rad se bavi inovativnom metodom koja omogućava EDM obradu elektroneprovodljivog keramičkog materijala, pod nazivom elektroerozivna obrada sa pomoćnom elektrodom (AEEDM). Drugim rečima, predstavlja kombinaciju klasične EDM sa hibridnom pomoćnom elektrodom. Cilj istraživanja je da se pronađe uticaj dužine trajanja impulsa na hrapavost obrađene površine. Za postavljene uslove obrade utvrđeno je da se hrapavost obrađene površine povećava povećanjem dužine trajanja impulsa. Treba naglasiti da se metoda sa pomoćnom elektrodom koristi samo pri obradi električno neprovodljivih materijala.*
Ključne reči: *EDM, hibridna pomoćna elektroda, dužina trajanja impulsa, hrapavost obrađene površine*

1. INTRODUCTION

Electrical discharge machining is a widely used and economically justified process that has wide applications and is most commonly used in the manufacture of tools for shaping materials, special and micro-particles, prototypes, etc. This machining can process all electrically conductive materials, but the main justification lies in the processing of high-alloy steels, difficult-to-cut steels and metal-ceramics. Recently, there are various innovative directions in the development of electrical discharge machining to process other modern but difficult-to-machine advanced materials [1].

EDM is used in the machining of electrically conductive materials, but its fundamental application is justified mainly in the machining of parts of specific structures made of materials that are difficult to cut [2]. In order to increase the efficiency of electrical discharge machining of modern engineering materials, existing or innovative EDM processes are constantly being researched and improved. Recently, a possible technological improvement of EDM process is achieved by an innovative method, such as Assisted Electrode Electrical Discharge Machining (AEEDM).

Compared to classical electrical discharge machining, only a few dozen papers have been published in the field of AEEDM. From the literature sources dealing with this field, some prominent works have been selected, on the basis of which an overview of the state of the art in the mentioned field has been presented. It should be emphasized that the assisting electrode method is used only in EDM of electronically non-conductive materials.

The foundations of Assisted Electrode Electrical Discharge Machining were laid in the early 1990s. The first appearance of EDM technology with an assisting electrode in academic circles was recorded in 1995 by Japanese scientists Fukuzawa et al [3]. In this paper, they described a new method that enables EDM of non-conductive ceramic materials using a metal plate (assisting electrode) bonded to the workpiece and tools made of soft metal material. They concluded that discharge machining is achieved thanks to the modification of the ceramic surface, i.e. the continuous creation of an electrically conductive layer.

In this context, non-conductive ceramic materials can be machined by the EDM process using a supporting electrode layer [4]. The EDM process with assistng electrode is shown in Figure 1. The surface of the workpiece is covered with an electrically conductive material, allowing an initial electrical discharge, i.e., a discharge between the tool and the supporting electrode. This is followed by continuous erosion through the

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conductive layer to the workpiece material, on which the carbon layer (pyrolytic layer) is formed. During electrical discharge machining, a hydrocarbon layer is continuously formed on the workpiece, which is responsible for the stability of the process.

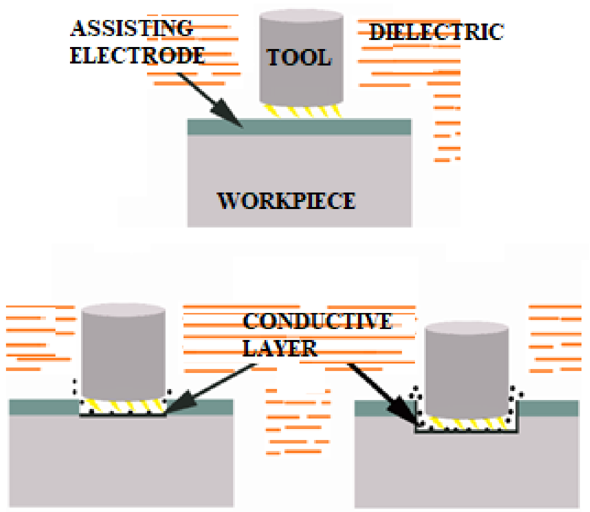

Fig. 1. Assisted Electrode Electrical Discharge Machining (AEEDM)

In order for AEEDM to process electrically nonconductive ceramic materials, hydrocarbon-based seed dielectrics could be used. By converting electrical energy to thermal energy, the resulting high temperature visibly affects the dielectric in the region of the discharge channel. In the absence of oxygen in the region, the high temperature honestly leads to thermochemical decomposition of the dielectric [5]. The decomposition of materials under the influence of high temperature, without the influence of other forces, is called pyrolysis [6]. As a result of pyrolysis of the hydrocarbon-based dielectric, a carbon layer (pyrolytic layer) is formed. The resulting carbon layer is represented by the molten layer formed during EDM metal processing and is similar in structure to graphite, which makes it electrically conductive [6]. The electrically conductive layer is formed from electrically conductive particles, mainly carbon, formed by the dissolution of dielectric components and tool wear products during discharge [7]. This electrically conductive layer is essential for stable discharge during the AEEDM process.

Various metal foils can be used as assisting electrodes. The most common are metal foils made of aluminum and copper, which are mechanically applied to ceramics. The main advantage of this method is simplicity [8]. The main disadvantage of tightening the metal foil on ceramics is the lack of solid contact between the metal and the ceramic. Due to the lack of direct contact between the foil and the ceramic, the formation of the carbon layer is difficult, which leads to the instability of the AEEDM process, i.e., the interruption of the processing. The combination of metal foil and graphite coating is called hybrid assisting electrode. The metal foil provides robustness, i.e. it ensures the strength of the auxiliary electrode, while the graphite coating acts as an adhesive between the metal foil and the ceramic. The influence of the assisting electrode material on the technological properties of the AEEDM was analyzed by the authors Tani et al. In their work [9], they machined zirconia (ZrO_2) with copper and graphite tools. They found that the carbon layer was not completely generated by copper tools, resulting in a rough surface roughness. When a graphite tool was used, a significant reduction in the roughness of the treated surface was observed. In the previous two studies, they concluded that after the removal of the assisting electrode material, an electrically conductive carbon layer is continuously formed on the ceramic surface, without which machining would not be possible. The same authors concluded in the case of silicon nitride machining [10] that reducing the pulse length below 24 s improves the roughness of the treated surface, since in this way the excessive pulse length is prevented, which directly increases the discharge energy.

This research relates to the electrical discharge machining of electronically nonconductive ceramics. In order for electronically non-conductive materials, especially ceramics, to be processed by EDM, it is necessary to establish an electrical contact. By applying an electrically conductive layer (referred to as an assistng electrode - AE) to the ceramic surface, EDM machining of electrically non-conductive ceramic materials is made possible. One of the representatives of electronically non-conductive ceramics that has been used in this research is zirconia - ZrO_2. Very few works have investigated the influence of the main parameters of AEEDM, such as pulse duration, on surface roughness.

2. EXPERIMENTAL SETUP

The experiments were carried out on a die-sinking EDM machine Agie Charmilles of the SP1-U type, Figure 2. The isotropic graphite with a cross-section of 10×10 mm^2 was used as an electrode for machining insulating zirconium oxide ZrO_2. Before conducting the experiments, all tools were surface ground to ensure normality with the workpiece.

Fig. 2. EDM machine Agie Charmilles of the SP1-U type

For AEEDM of non-conducting materials to be possible, a hydrocarbon-based dielectric must be used. The commercial mineral oil (Castrol Ilocut 180) with a flash point of 100°C was used as the dielectric fluid in this study. As assisting electrode, the combination of metal foil and graphite coating used in this research. This type is called hybrid assisting electrode. A basic technique was developed in which a graphite layer (Graphite 33 lacquer) and an adhesive layer of copper foil (3M grade 1181) were applied to the workpiece surface.

The surface roughness measurements for the eroded surface were carried out using Perthometer, Mahr Surf PS1. The average surface roughness R_a [µm] was used to quantitatively assess the quality of the machine surface.

In conducting the experiment, a lateral leaching was used with a dielectric with a flow rate of 20 l/min, through a nozzle with a diameter of 4 mm and the other with a nozzle with a cross section of 2x8 mm. The tool lift-off time was 2 seconds at a distance of 1.5 mm. The erosion time of each experimental point was 60 min.

For machining metallic materials, a duty factor of up to 95% is recommended. However, when machining ceramics, the increase has its limit to allow the formation of a carbon layer under the given machining conditions. According to sources from the literature, when machining ceramics, the duty factor ranges from 20 ÷ 50% [11, 12]. When machining with higher discharge currents and pulse duration, it is desirable that this coefficient moves to lower values.

Since the upper limit of discharge current of 2 A was chosen in this study, which is a relatively small discharge current, the chosen duty factor for machining with zirconia is 50%. Mostly, the open-circuit voltage can be set to 100 V or 300 V. When starting the machine tool with a voltage of 100 V, it was difficult to start the AEEDM ZrO_2 due to the extremely low energy. To increase the energy, the machine has the option to turn on the auxiliary discharge current (high voltage current). When this option is enabled, the open circuit voltage is 300 V.

Under these processing conditions, it cannot affect the discharge voltage. During processing, a voltage value of about 240 V is automatically determined, which is measured by a DC voltmeter.

In this study, the negative polarity of the tool was used in AEEDM of zirconia. According to literature [4, 13, 14], when AEEDM insulating materials with negative tool polarity, the process is much more stable. Also, the transition time from the assisting electrode layer to the carbon layer is shorter than with the positive polarity of the tool.

3. RESULTS AND ANALSYS

By applying an electrically conductive layer (Assisting Electrode) to the surface of the workpiece, it is possible to machine electronically non-conductive ceramic materials, which is called Assisting Electrode Electrical Discharge Machining. The assisting electrode allows the initial electrical discharge between the tool and the workpiece. After removing the assisting electrode layer, the dielectric decomposes due to the high temperature in the discharge zone, whereupon carbon particles are deposited on the surface of the workpiece and form an electrically conductive layer.

Before planning experimental trials, it is necessary to determine the range of variation of appropriate input parameters of machining, as well as other factors whose values are constant during the experiment. Based on the available literature sources and preliminary experimental studies, suitable conditions for the electrical discharge machining of ZrO_2 were assumed.

The magnitude of the discharge current is limited by the dimensions of the frontal surface of the electrode, i.e. the current density. Here, the projection in the plane perpendicular to the direction of movement of the tool is taken as the governing surface of the tool. According to the previously published studies in the field of AEEDM, discharge currents up to 6 A have been used for electrode areas up to 1 cm^2 [15].

It is clear that as the discharge current increases, the discharge energy increases, resulting in better machining efficiency, but at higher values of discharge energy, the machining may become unstable, leading to the appearance of large craters on the workpiece surface, Figure 3.

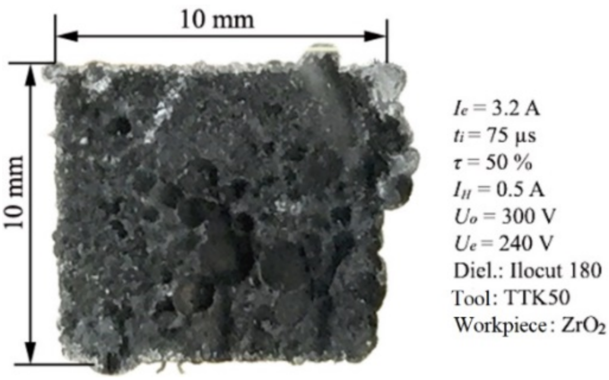

Fig. 3. Preliminary experimental trial, electrical discharge machining of ZrO_2

Under the preliminary machining conditions: Discharge current 3.2 A, pulse duration 75 µs, duty factor 50%, auxiliary discharge current 0.5 A, open circuit voltage 300 V, the treated surface was obtained with high roughness, which could not be measured.

It is clear that as the discharge current increases, the discharge energy increases, resulting in better machining efficiency, but at higher values of discharge energy, the machining may become unstable, leading to the appearance of large craters on the workpiece surface. Accordingly, in this study on the electrical discharge machining of zirconia, the selected discharge current has been varied in the range of 1.5 A.

The purpose of the auxiliary discharge current in these experimental studies is to increase the energy to allow the transition of the assisting electrode layer into the carbon layer, without which the machining of insulating materials would not be possible. When the auxiliary current is activated, the machine control automatically switches the open circuit voltage to 300 V. The pulse duration is the time of the pulse in microseconds for which current flows in each cycle.

During this time, the voltage is built up between the tool and the workpiece. According to the research published in the papers, the upper limit of the pulse duration for machining zirconia was 200 µs.

Accordingly, a discharge current of 1.5 A was used to investigate the effect of pulse duration on the surface roughness of AEEDM zirconia. The pulse duration was varied in three levels: 42, 75 and 110 µs. The test results are shown in Table 1.

Exp no.	I [A]	ti [µs]	Ra [µs]
1	1.5	42	9
2	1.5	75	10
3	1.5	110	13

Table 1. Table experimental trials

As the pulse length increases, the surface roughness increases at a constant discharge current. A test experiment was conducted at a constant discharge current of 1.5 A for the machining conditions set to determine the pulse duration up to which the erosion process is stable.

It was found that for pulse lengths above 100 µs, Figure 4. For pulse durations below 42 µs, no carbon layer formed on the ceramic surface, which resulted in the AEEDM ZrO_2 process not being used.

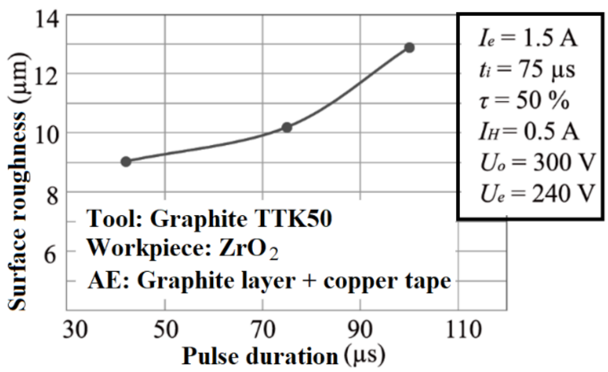

Fig. 4. Influence of pulse duration on surface roughness in AEEDM of ZrO_2

4. CONCLUSION

The innovative development direction of Assisted Electrode Electrical Discharge Machining presented in this paper has elevated EDM to a higher level, especially from the aspect of machinability of electrically non-conductive materials. However, the research conducted in this paper covers only a small part of the field of electrical discharge machining of advanced engineering materials.

Based on previous research, the most influential parameter is the discharge current. However, very few works have investigated the extent to which pulse duration increases. According to the presented research, at constant discharge current, there is a pulse cutoff length of 100 µs after which the AEEDM zirconium process becomes unstable.

The investigations in this work open some questions of new scientific knowledge, which impose themselves as guidelines for further development and future application of innovative methods of electroerosive treatment.

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