

Oxidized tool electrodes for optimized electro-discharge drilling

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Abstract

The production of components for automotive and aerospace industry by conventional machining is still limited by hardness and strength of the workpiece materials. Electro-discharge drilling is used for machining electrically conductive materials without any limitation due to mechanical properties.

Electro-discharge drilling causes debris in the working gap, which leads to arcs and short circuits on the lateral surface with negative effects on processing results and process duration. Due to these arcs and short circuits limited drilling depth, increased tool wear, conicity of boreholes and process instabilities are still challenges in electro-discharge drilling.

In this work, a new approach for passivation of the tool electrode material by oxidation is shown. Different oxidation processes for tool electrodes made of brass were applied and analysed.

Surface modified tool electrodes were used for electro-discharge drilling of Elmax, SuperClean from the company VOELSTAPINE AG, Linz, Austria. The investigation was carried out on the machine tool AGIETRON Compact 1 from the company AGIE SA, Losone, Switzerland, for machining of through holes with a depth of $t = 33.5$ mm using different surface modified tool electrodes with a diameter of $d = 0.8$ mm.

First results show a reduction of the erosion duration by 20 % for the application of thermally oxidized brass.

The investigation of different defined oxide layer thicknesses and electrical resistances for specific applications are part of this ongoing work. This work is funded by the German Research Foundation (DFG).

Type the keywords here: drilling EDM, oxidation, efficiency

1. Introduction

The production of high-precision components with micro-scale features is of growing importance in almost all industrial sectors. Due to the high requirement and complexity in the field of micro-machining, UHLMANN ET AL. [1] proposed a new process chain. Furthermore, the state of the art with the advances and limitations of current micro-machine tools in the field of micro-turning, micro-milling, grinding and different variants of electro-discharge machining were shown.

Electro-discharge drilling was presented as a key technology of manufacturing advanced fuel injection nozzles and cooling holes in turbine blades made of super alloys in the automotive and aerospace industry, respectively [2]. For the consumer market micro-holes are used in various micro-components as in watches and cameras [3]. The non-conventional process of electro-discharge drilling is capable for machining electrically conductive materials with high mechanical properties such as tool steel, carbides, titanium alloys and super alloys.

An everlasting challenge in this field is the formation of debris in the working gap of dielectric fluid resulting from the thermal removal process. The metallic nature of these debris acts as an electrical conductor in the electro-discharge drilling process, leading to arcs and short circuits. To remove debris and its related arcs and short circuits pressure flushing is utilized to evacuate the debris along the lateral working gap s_l . Although the process has been significantly improved, arcs and short circuits still occur on the lateral surface of the tool electrode. These arcs and short circuits lead to increased process

instability, erosion duration t_{ero} , tool wear Δl_e , conicity of boreholes α and a formation of a white layer across the machined surface of the workpiece electrode with a reduced mechanical endurance f [4]. Therefore, a surface modification of the tool electrode to reduce the number of arcs and short circuits is required to achieve precise machining of boreholes with high aspect ratios a .

In this work, a new approach for passivation of the lateral surface of brass tool electrodes by oxidation according to UHLMANN ET AL. [5] is shown. It is expected, that the oxide layer on the surface of the tool electrode increases the electrical resistance R , which decreases the probability of the occurrence of arcs and short circuits. An improved process stability, decreased erosion duration t_{ero} and tool wear Δl_e is expected.

2. Materials and Methods

2.1. Thermal oxidation of brass

Prior the oxidation, the brass tool electrodes with an outer diameter of $d_o = 0.8$ mm, an inner diameter of $d_i = 0.3$ mm and a length of $l = 150$ mm from the company EDM DEUTSCHLAND GBR, Kahl am Main, Germany, have to be cleaned. Therefore, a diamond paste with a grain size of $s_g = 1$ μm from the company STRUERS GMBH, Dresden, Germany, was applied to remove grease films and natural oxidation layers to provide identical conditions before oxidation. The tool electrodes were cleaned with an ultrasonic bath device Sonorex RK 100 from the company BANDELIN, ELECTRONIC GMBH & CO. KG., Berlin, Germany. To prevent a natural oxidation, ethanol was applied. Afterwards, the brass tool electrodes were either thermally oxidized at an

oxidation temperature of $\vartheta_{\text{oxi}} = 250\text{ }^{\circ}\text{C}$ or $\vartheta_{\text{oxi}} = 550\text{ }^{\circ}\text{C}$ by the laboratory-type drying cabinet 6120 or furnace 110 from the company HERAEUS DEUTSCHLAND GMBH & CO. KG., Hanau, Germany, respectively. The oxidation parameters are listed in Table 1. After the oxidation process, the oxidized tool electrodes were cooled to ambient temperature ϑ in air on a fireclay brick.

Table 1 Chosen parameters for the oxidation of tool electrodes

Oxidation atmosphere	Oxidation temperature ϑ_{oxi}	Oxidation time t_{oxi}
Air	250 $^{\circ}\text{C}$	1 min; 10 min; 30 min; 60 min
H ₂ O		
O ₂	550 $^{\circ}\text{C}$	

On the lateral surface of the tool electrode, the specific electrical resistance ρ was determined using the four-point probe method. The high-precision multimeters 5000 and 5001 from the company PREMA SEMICONDUCTOR GMBH, Mainz, Germany, were used for this purpose.

2.2. Electro-discharge drilling

Surface modified tool electrodes were used for electro-discharge drilling of Elmax, SuperClean from the company VOELSTAPINE AG, Linz, Austria. The investigation was carried out on the machine tool AGIETRON Compact 1 from the company AGIE SA, Losone, Switzerland, for machining through holes with a depth of $t = 33.5\text{ mm}$ using different surface modified tool electrodes with a diameter of $d = 0.8\text{ mm}$. An inner pressure flushing with a pressure of $p = 50\text{ bar}$ through the single channel electrode was used. The erosion duration t_{ero} as well as the tool length wear Δl_e were measured.

3. Results

3.1. Oxidation

Figure 1 shows the dependance of the specific electrical resistance ρ on the oxidation duration t_{oxi} .

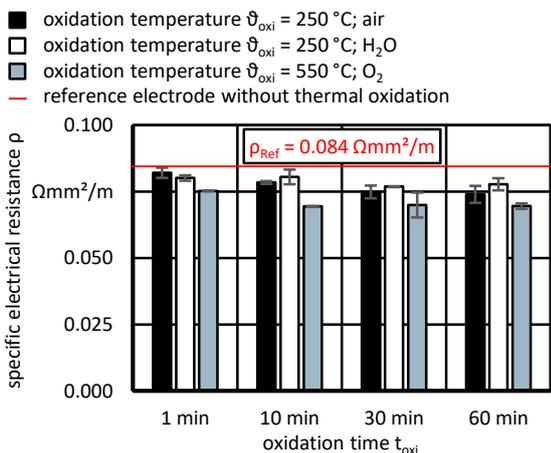


Figure 1. Specific electrical resistance ρ of oxidized tool electrodes

Due to the oxide layer, a higher specific electrical resistance ρ is expected. However, the specific electrical resistance ρ decreased with a higher oxidation time t_{oxi} . By using an atmosphere of air, the specific electrical resistance ρ could be reduced from $\rho_{\text{Ref}} = 0.084\text{ Ohm}\cdot\text{mm}^2/\text{m}$ to $\rho = 0.082\text{ Ohm}\cdot\text{mm}^2/\text{m}$ at an oxidation time of $t_{\text{oxi}} = 1\text{ min}$, whereas the specific electrical resistance ρ was reduced to $\rho = 0.074\text{ Ohm}\cdot\text{mm}^2/\text{m}$ at an oxidation time of $t_{\text{oxi}} = 60\text{ min}$. This can be explained by the thermal exposure of the tool electrodes. For brass, stress-relief annealing occurs at a temperature of $\vartheta_{\text{oxi}} = 250\text{ }^{\circ}\text{C}$. This leads to a decreased number of dislocations and defects resulting in a decreased specific electrical resistance ρ . The tool electrodes

heated at an oxidation temperature of $\vartheta_{\text{oxi}} = 550\text{ }^{\circ}\text{C}$ show a decreased specific electrical resistance of $\rho = 0.070\text{ Ohm}\cdot\text{mm}^2/\text{m}$ as well as a reduced hardness H and strength f due to recrystallization. Thus, these tool electrodes were unsuitable and not used for electro-discharge drilling. An error could be caused by the low thickness t of the oxide layers. As a result the measuring of the specific electrical resistance ρ could be influenced by unoxidized parts of the surface of the tool electrodes. The oxide layer thickness t was not measured.

3.2. Electro-discharge drilling

Figure 2 shows the erosion duration t_{ero} as well as the tool length wear Δl_e of the oxidized tool electrodes. Three through holes were drilled with each tool electrode configuration.

Tool electrode configuration:

Ref reference electrode without thermal oxidation

I oxidation time $t_{\text{oxi}} = 1\text{ min}$, air

II oxidation time $t_{\text{oxi}} = 1\text{ min}$, H₂O

III oxidation time $t_{\text{oxi}} = 60\text{ min}$, air

IV oxidation time $t_{\text{oxi}} = 60\text{ min}$, H₂O

Processing results:

■ erosion duration t_{ero}

□ tool length wear Δl_e

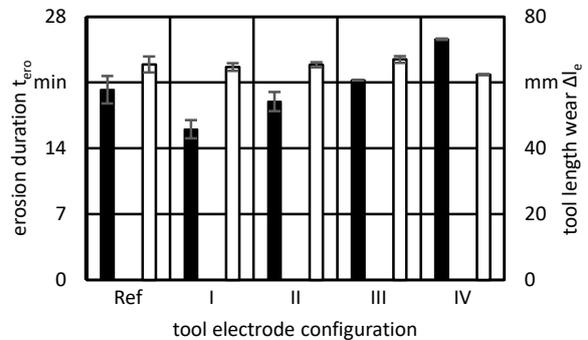


Figure 2. Processing results of oxidized tool electrodes

The lowest erosion duration t_{ero} was achieved by the tool electrode configuration I, which led to a reduction of the erosion duration from $t_{\text{ero,Ref}} = 20.2\text{ min}$ to $t_{\text{ero,I}} = 16.0\text{ min}$. Longer oxidation times t_{oxi} resulted in an increased erosion duration t_{ero} . The tool length wear was reduced from $\Delta l_{e,\text{Ref}} = 65.5\text{ mm}$ to $\Delta l_{e,I} = 64.8\text{ mm}$.

4. Conclusion and Outlook

The oxidation of brass tool electrodes showed promising results regarding process stability, erosion duration t_{ero} and tool length wear Δl_e . Nevertheless, thermal exposure during oxidation of the tool electrodes leads to a stress-relief annealing or recrystallization. This results in a reduction of the electrical resistance R , hardness H and strength f and effects the electro-discharge drilling process directly. Further investigations address the oxidation behaviour of different electrode materials and the effect on the electro-discharge drilling process. This work is funded by the German Research Foundation (DFG).

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