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Application of tool electrodes oxidised with humid and dry air during the electro-discharge drilling of MAR-M247 alloy

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Abstract

The requirements and challenges of machining advanced materials in the field of aerospace, automotive and tool industry are increasing constantly. Due to their mechanical properties, cutting of high-strength materials such as superalloys is severely limited. Electro-discharge drilling can be used for the manufacturing of holes in hard to machine materials. Although electrical discharge machining (EDM) is successfully applied to the machining of holes in turbine blades, a lack of performance and challenges concerning the geometrical accuracy still remain. By applying inner flushing, the resulting electrically conductive debris is flushed through the lateral working gap, increasing the probability of arcs and short circuits. The resulting increased tool wear, conicity of the hole, limited hole depth and process instabilities are still challenging in electro-discharge drilling.

In order to decrease the effects of the arcs and short circuits, a surface modification is applied to increase the electrical resistance of the lateral surface of the tool electrode. As a result, the mentioned impairments occur less frequently due to decreased occurrence of arcs and short circuits in the lateral working gap. For the present investigation copper tool electrodes were thermally oxidised in dry and humid air with different durations and used afterwards for electro-discharge drilling of MAR-M247. The tests were carried out on the machine tool AGIETRON Compact 1 from the company GF AgieCharmilles, Losone, Switzerland. Holes with a depth of t = 11 mm were drilled using various surface-modified tool electrodes with a diameter of d = 2 mm. Oxidation with dry air and a extended oxidation time resulted in a 18 % lower erosion duration, accompanied by an increase of the linear wear of the tool electrode Δl_e below 10 %.

Keywords: Drilling EDM, oxidation, process efficiency

1. Introduction

Nowadays, the requirements and needs for high-tech applications have increased extremely. Consequently, technological innovations must also grow in order to machine advanced materials. These materials are characterized by high hardness H and strength f, for which conventional machining processes are not always sufficient. For the purpose of drilling holes in those materials, electro-discharge drilling is successfully used instead. Advanced fuel injection nozzles and cooling holes in turbine blades for the aerospace and automotive industry are few of the many applications for this machining process [1].

However, further challenges in the area of electro-discharge drilling are still remaining. The formation of debris in the working gap s of the dielectric fluid leads to arcs and short circuits. As a consequence, inner pressure flushing is used to remove those debris to avoid arcs and short circuits occuring on the lateral surface of the tool electrode. The resulting process instability, increased erosion duration t_{ero}, relative linear wear ϑ_l and the conicity of boreholes α still need to be addressed. To improve the process significantly, the tool electrodes were surface modified to reduce the probabilities of the occurrence of arcs and short circuits on the lateral area of the electrodes [2, 3].

In this work, the passivation was achieved by means of an oxidation of the tool electrode surface following the procedure according to Uhlmann et al. [4]. The oxidation duration t_{oxi} and the oxidation atmosphere have been varied with the objective to decrease the erosion duration t_{ero} and the linear wear of the tool electrode Δl_e.

2. Materials and methods

To achieve identical oxidation pre-conditions, the copper tool electrodes with an outer diameter of d_o = 2 mm and a length of l = 80 mm from the company EDM Deutschland GbR, Kahl am Main, Germany, have to be cleaned properly. For this, a diamond paste with a grain size of s_g = 1 µm from the company Strueers GmbH, Dresden, Germany, was used to remove the pre-existing oxidation layers. Afterwards the tool electrodes were cleaned in the ultrasonic bath device Sonorex RK 100 from the company Bandelin, Electronic GmbH & Co.KG, Berlin, Germany, using ethanol to prevent further natural oxidation.

The subsequent oxidation processes were carried out at an oxidation temperature of ϑ_{oxi} = 200 °C by the laboratory-type drying cabinet 6120 from the company Heraeus Deutschland GmbH & Co. KG, Hanau, Germany. No higher oxidation temperature ϑ_{oxi} was initially selected to avoid excessive loss of strength f due to recrystallization and grain coarsening. Tool electrodes with excessive loss of strength f can no longer be used for electro-discharge drilling. The oxidation parameters used for this investigation are given in Table 1. After the oxidation process, the tool electrodes were exposed to air on a fireclay brick until ambient temperature ϑ_a was reached. The oxidised tool electrodes were used for drilling blind holes in MAR-M247 on the machine tool AGIETRON Compact 1 from the company GF AgieCharmilles, Losone, Switzerland, with a sinking depth of e_s = 11 mm.

Table 1 Oxidation parameters of tool electrodes

Electrode configuration	Oxidation atmosphere	Oxidation temperature ϑ_{oxi}	Oxidation time t_{oxi}
I	dry air	200 °C	10 min
II			35 min
III	humid air		10 min
IV			35 min

Three runs are performed for each electrode configuration without inner flushing nor rotation to observe the effects of the oxidation and to maintain the reproducibility only. The process parameters are given in Table 2. The erosion duration t_{ero} as well as the linear wear of the tool electrode Δl_e were determined.

Table 2 Process parameters of electro-discharge drilling experiments

Discharge peak current i_p	Open circuit voltage $\hat{u}_i$	Discharge duration t_e	Pulse interval time t_0	Capacity C
117 A	160 V	32 µs	18 µs	1 µF

3. Results

3.1. Preparation by oxidation

Figure 1 shows the mass fraction of copper w_{CU} and the mass fraction of oxygen w_O as functions of the oxidation atmosphere and the oxidation time t_{oxi}.

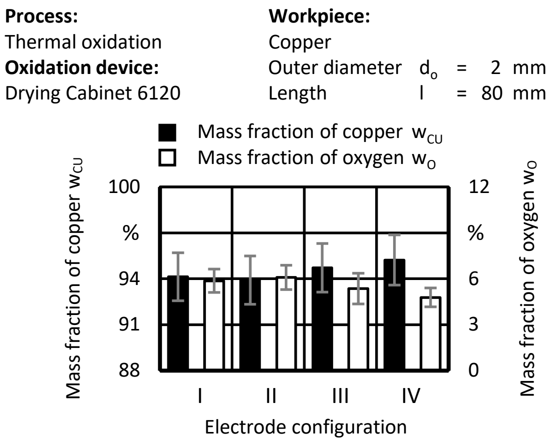

Figure 1. EDX results of different oxidised tool electrodes

The mass fraction of oxygen in the lateral area of the copper tool electrodes oxidised in dry air increases with the duration of exposure. The longer oxidation time t_{oxi} resulted in an increase from $w_{O,I}$ = 5.9 % to $w_{O,II}$ = 6.1 %. However, the mass fraction of oxygen was reduced from $w_{O,III}$ = 5.4 % to $w_{O,IV}$ = 4.8 % during oxidation in a humid atmosphere. Poorly adherent black particles were observered for electrode configuration III. It may be possible that the oxidation layer generated in the humid atmosphere is porous and delaminating with an increasing oxidation duration t_{oxi} due to thermal stresses σ_{th} between the oxidation layer and the core material. As a result, the mass fraction of oxygen w_O of electrode configuration IV is lower than of electrode configuration III.

3.2. Electro-discharge drilling experiments

Figure 2 shows the erosion duration t_{ero} and the linear wear of the tool electrode Δl_e of the oxidised tool electrodes, compared to the unoxidised reference tool electrode (Ref).

Generally, it could be proven that a longer oxidation duration t_{oxi} can lead to a decreased erosion duration t_{ero}. But still a high margin of error occurred. The lowest erosion duration t_{ero} was accomplished by electrode configuration II, which led to a reduction of the erosion duration by 18 %, from $t_{ero,Ref}$ = 20.4 min to $t_{ero,II}$ = 16.8 min.

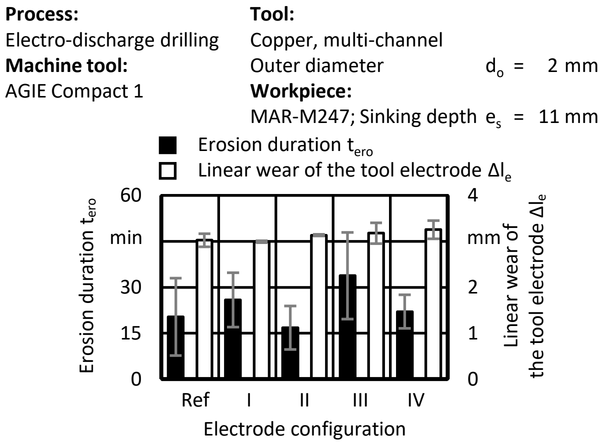

Figure 2. Processing results of oxidised tool electrodes

Although the mass fraction of oxygen of electrode configuration IV with $w_{o,IV}$ = 4.8 % is lower than the one of configuration III with $w_{O,III}$ = 5.4 %, this configuration also led to a much lower average erosion duration of $t_{ero,IV}$ = 22.0 min in comparison to $t_{ero,III}$ = 33.8 min. This leads to the conclusion that the mass fraction of oxygen w_O may not be the only influence on the erosion duration t_{ero}. Following the extended oxidation duration t_{oxi} of electrode configurations II and IV compared to I and III, recovery processes due to heat treatment could also be a factor, influencing the erosion duration t_{ero}. The linear wear of the tool electrode increases by 10 % at most, from $\Delta l_{e,Ref}$ = 3.0 mm to $\Delta l_{e,IV}$ = 3.3 mm.

4. Conclusion and outlook

The oxidation of copper tool electrodes showed promising results regarding erosion duration t_{ero} and the linear wear of the tool electrode Δl_e as part of prestudies regarding the oxidation atmosphere. A decrease of the average erosion duration t_{ero} by 18 % could be achieved with a longer oxidation time t_{oxi} but with contradictory mass fractions of oxygen w_O. Thus, these experimental trials open up further research questions that need to be investigated. Further experiments will be performed to explain correlations by using parametric statistical tests. Also, the investigation of deeper holes will reveal the effects on the conicity α which should decrease due to the oxidation layer. Different heat treatments of tool electrodes with and without oxidation are to be compared. The effects of crystal recovery and recrystallisation on electro-discharge drilling shall be investigated likewise. Also, chemical oxidation can be carried out to analyse the effects of the oxidation without any heat treatment at ambient temperature ϑ_a. Further investigations regarding electrode materials and their effects on the electro-discharge drilling process will be addressed. This work is funded by the German Research Foundation (DFG).

References

[1] Kliuev, M. et al.: EDM drilling and shaping of cooling holes in Inconel 718 turbine blades. Procedia CIRP 42 (2016), p. 322 - 327.

[2] Uhlmann, E. et al.: Oxidized tool electrodes for optimized electro-discharge drilling. Proc. 20th Int. euspen Conf., Geneva, Switzerland, 2020.

[3] Uhlmann, E. et al.: Helical electrodes for improved flushing conditions in drilling EDM for MAR-M247. Proc. 18th Int. euspen Conf., Venice, Italia, 2018.

[4] Property right WO002019137968 Publication (2019-07-18). Fraunhofer Gesellschaft. Streckenbach, J. et al.: Method for Producing a Tool Electrode, Tool Electrode, and Method for using same.