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Electro-discharge drilling with MP-based carbon fibre electrodes

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Abstract

For the electro-discharge drilling of micro-holes with small diameters D the production and the guidance of the tool electrode are most challenging. For holes with diameters D ≤ 50 µm the required electrodes have to be produced by electro-discharge dressing, which leads to a considerable increase in the production effort as well as the production costs. The small diameters 5 µm ≤ d ≤ 15 µm as well as the good electrical conductivity κ of carbon fibres make it possible to use a single carbon fibre as an electrode for electro-discharge drilling. The paper presents the results of experiments with non-rotating single carbon fibres as tool electrodes for electro-discharge drilling. The process parameters were optimised for the machining of through-holes in a workpiece made of stainless steel 1.4310 with a thickness h = 20 µm and h = 50 µm respectively.

Keywords: Electro-discharge drilling, carbon fibre, micro-machining

1. Introduction

Electro-discharge drilling is used in industrial applications for the machining of micro-holes with diameters D ≥ 50 µm and aspect ratios of l/D ≤ 20 [1, 2]. The current limit of electro-discharge drilling is the machining of a hole with a diameter D = 6.5 µm and aspect ratio of l/D = 7.5, which was machined under laboratory conditions [3]. Challenges in electro-discharge drilling of holes with small diameters D exist in the manufacturing and guiding of the tool electrode. For holes with diameters D ≤ 50 µm the required electrodes must be produced by electro-discharge dressing, which leads to a considerable increase in production effort as well as production costs. As an alternative for usage of conventional electrodes single carbon fibres can be used due to the small diameters d and high electrical conductivity κ.

The material used for the production of the carbon fibres are basically polyacrylonitrile (PAN) and mesophase pitch (MP). The PAN-based carbon fibres have a diameter of 5 µm ≤ d ≤ 7 µm and MP-based carbon fibres of 7 µm ≤ d ≤ 15 µm [4]. The lattice structure of both types is comparable to graphite, although MP-based fibre are more similar than PAN-based. Thus, MP-based carbon fibres have a higher thermal and electrical conductivity κ in comparison with PAN-based carbon fibres.

Trych-Wildner [5] investigated the feasibility of PAN-based carbon fibres with a diameter d = 7 µm as electrodes for electro-discharge drilling of micro-holes in steel 100Cr6. The basic feasibility was demonstrated by the drilling of shaped holes, although a large number of problems emerged. Thus, the maximum reached depth was h_{max} ≈ 13.5 µm, whereby the geometry of the holes varied greatly. Trych-Wildner [4] showed that the hole diameter D dependents on the discharge energy W_e, as well as the electrode length l_e, and varied between 16 µm ≤ D ≤ 32 µm.

Zhang et al. [6] compared the performance of tungsten electrodes and carbon fibre electrodes by machining of micro-holes in stainless steel. They established that the material removal rate V_w reached with carbon fibre electrodes was not much lower compared to tungsten electrodes. Thus, the machining time t_{ero} of through holes in a plate with a thickness of h = 30 µm was t_{ero} ≈ 30 min with tungsten electrodes and t_{ero} ≈ 35 min with carbon fibre electrodes. On the other hand, the electrode preparation time t_{prep} was significantly lower in case of carbon fibre electrodes. The preparation time t_{prep} of carbon fibre electrodes was t_{prep} ≈ 30 min, whereas the preparation and machining of tungsten electrodes with a diameter d = 7 µm required about t_{prep} ≈ 5 h.

Currently no scientific evidence exists for the electro-discharge drilling with MP-based carbon fibre electrodes. Therefore, investigations targeted on electro-discharge drilling with MP-based carbon fibres were carried out at the Institute for Machine Tools and Factory Management IWF of the Technische Universität Berlin.

2. Experimental setup

MP-based carbon fibres of the type XN-90-60S with the diameter d = 10 µm produced by the company Nippon Graphite Fiber Corporation, Japan, were applied as electrodes, see figure 1. Since the carbon fibre electrodes have small diameters d a special clamping device was developed. It consists of two copper plates which clamp a carbon fibre.

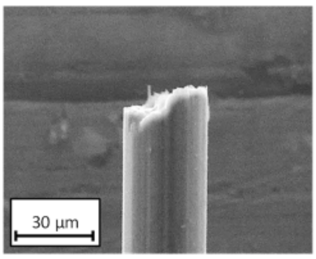

Figure 1. SEM image of MP-based carbon fibres of the type XN-90-60S

The investigations were carried out using an Agie Quadraton machine together with a generator of the type Agietron Spirit 2 from the company GF AGIE CHARMILLES, Switzerland. The machine tool is equipped with a current source for static impulse discharges and a relaxation micro-generator for capacitance discharges.

Samples made of stainless steel 1.4310 with a thickness of h = 20 µm and h = 50 µm were used as workpieces. Since carbon fibre electrodes are very flexible and had no guidance, no active flushing during the tests was applied. A fully synthetic mineral oil of the type IonoPlus® IME MH with a density of $\rho = 0.79\ g/cm^3$ (at $\vartheta = 15$ °C) and viscosity $\eta = 2.5\ mm^2/s$ (at $\vartheta = 40$ °C) of the company OELHELD GMBH, Germany, was used as a dielectric fluid.

3. Process investigations

At first, the investigations focused on the identification of proper process parameters. After that, the process was optimized with regard to the machining time t_{ero}. The process optimisation was carried out by varying the energy W_e and influencing process parameters, which were systematically evaluated by methods of statistical Design of Experiments (DoE).

After optimisation the average machining time of the through holes in samples with a thickness h = 20 µm was $t_{ero} \approx 40$ s with an average diameter of 24 µm ≤ D ≤ 26 µm, see figure 2.

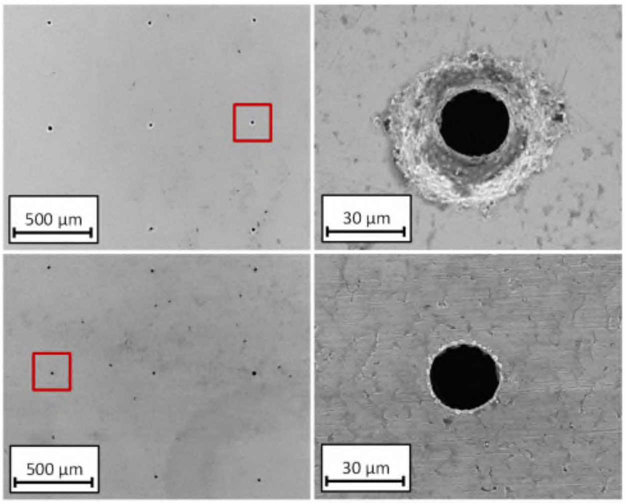

Figure 2. SEM image of holes in steel samples with a thickness of h = 20 µm: top – inlet, bottom – outlet

The average machining time of the through holes in samples with a thicknesses h = 50 µm was $t_{ero} \approx 180$ s with an average diameter of 26 µm ≤ D ≤ 30 µm, see figure 3.

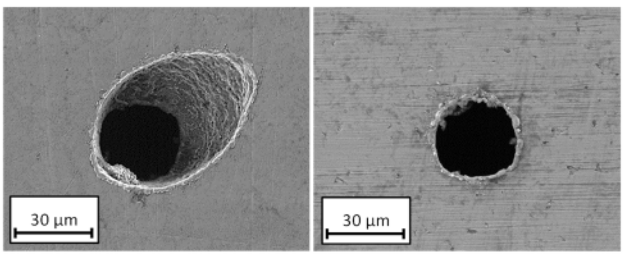

Figure 3. SEM image of holes in steel samples with a thickness of h = 50 µm: left – inlet, right – outlet

The low quality of the entry edges of the holes can be explained by the bad flushing conditions and the absence of guiding for the electrode. Due to the small contact surface A_K of the electrode and the small size of the working gap s, very often the machine control could not correctly respond to the process flow and the electrode collided with the workpiece. This led to a deflection of the electrode.

4. Summary and Outlook

The aim of the investigations was to prove a general applicability of MP-based carbon fibres as a tool electrode material for electro-discharge drilling of holes with small diameter D. In summary, the test results show that a technical feasibility of electro-discharge drilling with MP-based carbon fibre electrodes is possible. Since no information on the material removal mechanisms is known at present time, the next technological investigations will be carried out with regard to generator parameters and the dielectric fluid. In order to increase the quality of the entry edges of the holes and aspect ratio l/D, as well as to decrease the machining time t_{ero}, an effective flushing strategy and electrode guiding must be worked out.

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