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# Implementation of a handling system for using carbon fibres as tool electrodes in micro-ED drilling

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**Abstract**
Electrical discharge machining (EDM) processes represent an established process for the machining of complex geometries in hard to cut and electrically conductive materials. Nevertheless, micro-electrical discharge drilling still poses the challenge of machining holes with diameters $d_h \leq 50$ µm. The preparation of even smaller pin tool electrodes demands a great amount of non-productive time, which often involves the use of additional electrical discharge dressing processes for its manufacturing. A possible solution is the use of single carbon fibres with diameters 5 µm $\leq d_{el} \leq$ 10 µm as tool electrodes. The use of these single fibres comprises a challenge due to their geometrical and mechanical properties, e.g. diameter and brittleness. To overcome this challenge, an existing handling system for carbon fibres was re-designed considering the obstacles that arose with the use of previous versions of such systems. This includes the replacement of the liquid rubber coating of the movable clamping jaw in order to use foam rubber to achieve a better distribution of the clamping force that establishes the electrical contact between the carbon fibre and a conducting copper plate. The geometry of the borosilicate glass micro-pipette was redesigned to ensure an accurate positioning of the carbon fibre due to its inner tip diameter 15 µm $\leq d_t \leq$ 35 µm and to enable the use of fibre electrodes with a length of 15 mm $\leq l_e \leq$ 25 mm. This hinders the deflection of the fibre tip during the machining process and enables the precise guidance of the fibre. Furthermore, the developed handling system was implemented for performing single discharge experiments, in which parameters such as open circuit voltage, charge current and discharge capacity were varied in order to determine their influence on the material removal process.

Electrical discharge machining (EDM), micromachining, carbon, fibre

## 1. Introduction

Advances in technological applications require the implementation of processes that enable the manufacturing of precisely machined geometries. In this context, the increasing demand for products with dimensions in micro order opens a great possibility for micro technologies to have a high potential for future applications [1]. The wide variety of components in micro order and the various mechanical and thermal conditions to which a machine part is subjected to often makes the use of wear resistant materials a necessity. The machining of these hard materials increases the complexity of the used manufacturing processes. This complexity e.g. arises in the manufacturing of micro holes when diameters $d_h \leq 50$ µm are required. In these cases, the conventional machining processes are strongly limited in such a way that the use of thermic and electrochemical material removal processes is required [2, 3, 4].

The current limits of micro-ED drilling are in the production of holes with diameters $d_h < 3$ µm, which have been achieved with the use of tool electrodes made of tungsten and silicone. Nevertheless, these tool electrodes with submicron diameters need to be manufactured using time intensive processes such as WEDG and ECM [5]. As an alternative to the use of conventional tool electrodes, the use of single carbon fibres is possible given their small diameters and high electrical conductivity. The previously achieved diameters of holes machined using MP-based carbon fibres with $d_{el} = 10$ µm are 24 µm $\leq d_h \leq$ 30 µm with hole depths between 20 µm $\leq h_d \leq$ 50 µm [6]. Whereas the holes machined with PAN-based carbon fibres with $d_{el} = 7$ µm had diameters 16 µm $\leq d_h \leq$ 32 µm although with a smaller achieved maximum depth $h_{max} = 13.5$ µm [6]. Nevertheless the main challenge that arose in previous investigations when using carbon fibres as tool electrodes is the difficulty of the handling and in-process guidance and positioning of the fibres and therefore the reduced quality of the entry edges of the machined holes, shown by a mostly oval-shaped large entry hole diameter [6, 7]. Adressing this necessity of using carbon fibres in micro-ED drilling, a first version of a handling system for carbon fibres was developed [8]. Nevertheless, the usability of such a system proved to be challenging due to the necessity of using single carbon fibres of lenghts $l_e \geq 50$ mm.

## 2. Experimental setup

To investigate the applicability of carbon fibres as tool electrodes in micro-ED drilling, a previous version of the handling system had to be redesigned in order to improve the electrical contacting and accurate positioning of carbon fibres with reduced lengths 15 mm $\leq l_e \leq$ 25 mm. After assessing multiple factors influencing the successful use of carbon fibres as tool electrodes, it was determined that the borosilicate glass micro pipette used requires a different geometry. The electrical contacting system also needed an adaptation in order to better distribute the clamping force to avoid damaging the carbon fibres while ensuring an adequate electrical contacting.

Furthermore, to demonstrate the applicability of the redesigned handling system for micro-ED drilling, single discharge experiments were realised with multiple electrical parameter combinations.

### *2.1. Handling system*

The redesign of the handling system is based on MP-based carbon fibres of the type XN-90-60S with diameter $d_{el}$ = 10 µm, manufactured by the company Nippon Graphite Fiber Corporation, Japan.

As shown in Figure 1, the designed borosilicate glass micro pipette, manufactured by Hilgenberg GmbH, Germany, has a geometry that enables the guidance of single carbon fibres. Due to the inner diameter 2.5 mm ≤ $d_i$ ≤ 3.5 mm of the largest opening, the micro pipette facilitates the electrical contacting of the fibre while partially restricting the movement of the fibre. In contrast, the inner diameter of the micro pipette tip 15 µm ≤ $d_t$ ≤ 35 µm completely restricts the perpendicular movement of the carbon fibre. The short tip length 1.5 mm ≤ $l_t$ ≤ 2.5 mm enables the use of short carbon fibres. To stabilise the glass micro pipette positioned inside the housing of the handling system an O-ring with inner diameter $d_i$ = 2.3 mm is used.

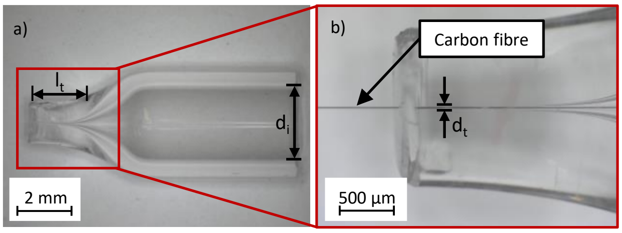


**Figure 1.** a) Glass micro pipette; b) detail of guided carbon fibre

Figure 2 shows all parts of the handling system in an exploded view. The metallic movable jaw ensures the electrical contacting and clamping mechanism on the copper plate using a spring. Foam rubber on top of the head of the metallic jaw facilitates an uniform distribution of the clamping force $F_c$ = 0.66 N and prevents damaging during the contacting.

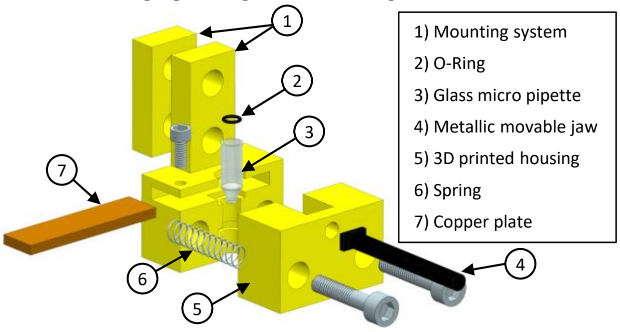


**Figure 2.** Exploded view of the handling system

### *2.2. Single discharge experiments*

A micro drilling system type Quadraton 1 and a generator type Spirit 2, both produced by the company GF AGIE Charmilles, Switzerland, were used, enabling small capacitance discharges. With the variation of electrical parameters and the use of discharge capacities 0.12 nF ≤ $C_e$ ≤ 0.45 nF calculated discharge energies 0.22 µJ ≤ $W_e$ ≤ 2.25 µJ can be achieved during the experiments.

Samples made of stainless steel 1.4310 with a thickness of h = 50 µm were used as workpieces. In order to better compare the effects that certain dielectric fluids may have on the functionality of the handling system, the single discharge experiments were carried out either using air or a synthetic mineral oil type IonoPlus IME MH by the company oelheld GmbH, Germany.

## 3. Process investigations

With the objective to confirm the usability of the handling system for correctly positioning the carbon fibre during electrical discharges, the resulting discharge craters were analysed after each experiment concerning the crater diameter and depth using the focus-variation system type InfitineFocus G4 from the company Alicona Imaging GmbH, Austria whith an objective lens with magnification V = 100. With the use of the handling system, craters with average depths $\overline{h_d}$ = 2.07 µm and diameters $\overline{d_h}$ = 45.26 µm were machined using synthetic oil as dielectric and applying average discharge energies of $\overline{W_e}$ = 0.59 µJ. In comparison, using air as dielectric, craters with average depths $\overline{h_d}$ = 3.09 µm and diameters $\overline{d_h}$ = 44.22 µm were machined, resulting from average discharge energies of $\overline{W_e}$ = 1.44 µJ. Figure 3 shows exemplary craters of single discharges.

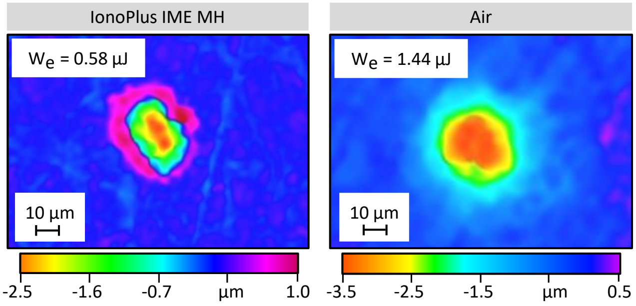


**Figure 3.** Focus-variation images of discharge craters in steel 1.4310

Compared to the machined holes from previous investigations without handling system [6], the entry diameters of the created single discharge craters are in average 25 % smaller and up to 40 % smaller when comparing the smallest machined craters $d_h$ ≤ 36 µm using calculated discharge energies $W_e$ ≤ 1.44 µJ. The machined craters as well as the machined holes from previous investigations imply that during the first discharges in micro-ED drilling using carbon fibres as tool electrodes, the discharge energy concentrates on the tip of the fibre, creating initial craters with diameters larger than three times the actual fibre.

## 4. Conclusion and further investigations

The objective of these investigations was to prove the applicability of the designed handling system for carbon fibres used as tool electrodes in micro-ED drilling. The obtained results show that the use of such a handling system enables a more accurate positioning of the fibre during the machining process, shown with the reduction of the size of initial crater diameters, in comparision with previous investigations which did not use such systems. Further investigations are carried out in order to provide extensive machining strategies based on single discharges.

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