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Process development and optimization in the die-sinking µ-EDM of micro molds for the dental industry

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Abstract
Experimental investigations carried out for this study aimed on developing a µ-EDM technology for producing smallest and finest structures with width of 230 µm and depth of 800 µm into a micro mold made of stainless steel. The main goal was to develop and to optimize the µ-EDM technology concerning the machining time, the tool wear of the electrode, and the form and positioning accuracy of the features. The metrological analysis using measuring distinct devices enabled the choice of the appropriate µ-EDM technology for producing the final cavities. Total machining time below 16 min as well as a tool electrode relative wear below 65 µm could be achieved. The cavity with micro structures could be produced at the hardened steel with respect to the requirements, including the exact size of structures (226 µm width) and precise position of cavity on the workpiece. The die-sinking µ-EDM confirmed to be a suitable technology for producing the cavities with micro-structures in hardened steel.
Keywords: Micro molds, µ-EDM machining and medical applications

1. Introduction

Despite the latest developments in the high speed machining (HSM) and micro-milling, the EDM (electrical discharge machining) and its modification named µ-EDM are technologies that will continuously be applied in the fabrication of complex and micro geometries in hard to machine materials. µ-EDM stands for the manufacturing of micro and miniature parts and structures applying modified machine tools and process technologies. µ-EDM is one of the process technologies applied in micro-production engineering, which can be defined as the manufacturing of products possessing at least one dimension or functional feature in the range of a micrometer. The µ-EDM, especially, is widely applied in the fabrication of micro molds due to the nearly non-existing machining forces, enabling finest structures on hardened steels, as well as due to the possibility of achieving high surface quality and high form accuracy. Moreover the µ-EDM is predestined for the production of single and small batches, as it is the case in the die and mold industry [1-3]. This paper deals with the development of a µ-EDM technology for producing smallest and finest structures in a micro mold for the dental industry.

2. Micro Mold, Equipment and Materials

This micro mold, made of high grade stainless steel Böhler M340 Isoplast (54 HRC), is to be applied in the micro injection molding of the dental disposable stick. The micro injection molding will be a two-stage process and both stick and micro mold are presented in **Figure 1**. The tip of the stick was the challenging feature to be manufactured by die-sinking µ-EDM. For this purpose, the machine tool Genius 1000 THE CUBE from company *Zimmer&Kreim GmbH Co. KG* was applied. This machine tool provides two important features necessary while developing and producing the structures mentioned: high positioning accuracy in all machining axes and automatic software compensation of electrode position in relation to the work piece. Electrolyte-copper E-Cu 58, presenting structures in the size of 130 µm and produced by µ-wire EDM-machining, was chosen as tool electrode and IonoPlus from Oelheld was applied as dielectric fluid.

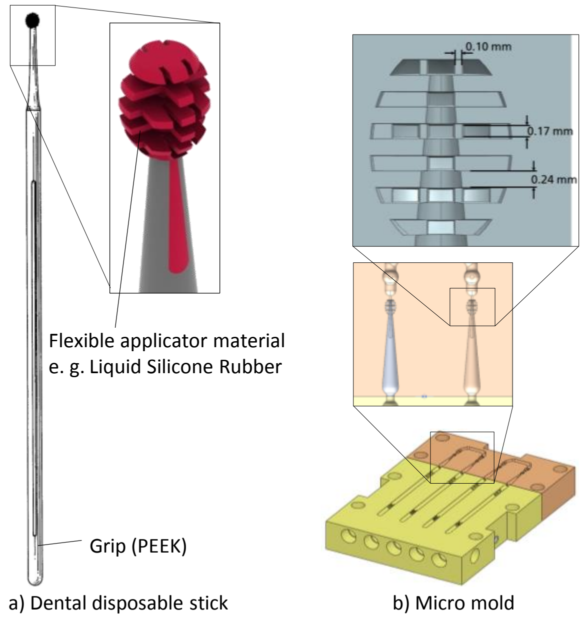

Figure 1. Dental disposable stick (a), micro tool and features (b)

3. Results and Discussion

The first task during the process development was to determine the suitable EDM-parameters, the working gap between parts and electrodes as well as the expected wear behaviour of tool electrode. Trials were conducted varying the discharge current $\hat{i}_e$, pulse duration t_i, pause duration t_0. A working gap of 10 µm and a relative tool wear below 2 % were determined for the chosen EDM parameters, which were: discharge current $\hat{i}_e$ = 1.5 A, pulse duration t_i = 10 µs, pause duration t_0 = 10 µs, ignition voltage u_i = 120 V, by applying anodic tool electrodes and static impulse discharges. This technology is called VDI18 at the machine tool and VDI states for the Association of German Engineers, which correlates defined VDI-classes with surface roughness Ra and Rt.

Following the optimization of the µ-wire EDM-technology for producing the tool electrodes, further five cavities with the defined micro-structures were produced by die-sinking µ-EDM applying distinct process strategies. These strategies included the variation of following parameters and/or process boundary conditions: flushing strategy, electrode change for wear compensation, and finally application of distinct polishing strategies. **Table 1** presents the applied strategies for machining the cavities as well as the results obtained. The strategy "polishing in Z-direction" was conducted applying relaxation discharges (100 nF) and inverted electrode polarity. Technology VDI15 derived from VDI18 with same voltage and discharge form and polarity, with following further parameters: discharge current $\hat{i}_e$ = 1 A, pulse duration t_i = 2 µs, interval pulse duration t_0 = 5 µs. VDI18 corresponds to an arithmetic surface roughness Ra = 0,8 µm, while VDI15 relates to Ra = 0,6 µm.

Table 1. Applied five strategies to produce the cavities

	Description of applied technology/strategy	Tool wear [µm]	Process time [min]
1	VDI 18 without flushing	44	29.28
2	VDI 18 + flushing	28	21.95
3	VDI 18 + wear compensation + polishing in all directions	29 + 3	20.8 + 6,3
4	VDI 18 + wear compensation + polishing in Z-direction	35 + 3	19.95 + 3,7 +7
5	VDI 18 reduced depth + wear compensation + VDI 15	18 + 60	12.3 + 4.3 + 9.7

Measurements of tool electrodes and produced cavities were conducted applying a scanning electron microscope (SEM) from Nikon and validated by an optical measurement device with Focus-Variation from Alicona. **Figure 2** presents the applied tool electrodes.

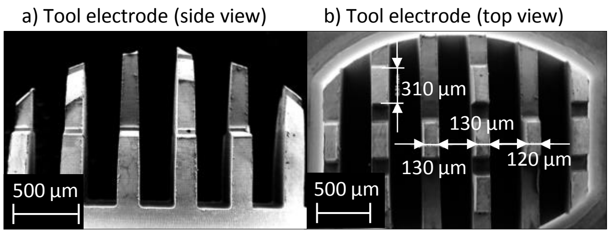

Figure 2. Applied tool electrode

The µ-EDM machining without flushing leads to form errors at the produced cavities. This is due to the accumulation of debris in the machining area, which leads to process instability and false discharges (Figure 3-a). The flushing enabled also a faster machining of the cavities reducing the machining time for roughing from 29.3 min down to 20 min. Strategy 3 with a polishing step in all directions X, Y and Z lead to a high material removal at thin walls and subsequently form errors at the workpiece (Figure 3-b). The polishing strategy 4 (Figure 3-c) using relaxation discharges only in the Z-direction enabled similar results as those achieved with strategy 5 (Figure 3-d). However, the machining time was slightly higher and therefore it was decided to apply strategy 5 in the fabrication of the final cavity. **Figure 3** presents the produced cavities prior and after process optimization (strategies 1, 3, 4 and 5).

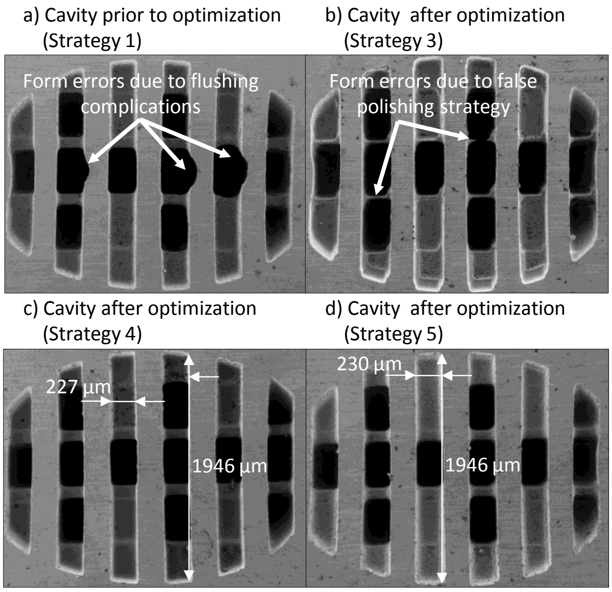

Figure 3. Produced cavities applying distinct strategies

Strategy 5 was applied for the final machining of the cavity at the workpiece and the results were measured applying Focus-Variation (**Figure 4**). The position of the cavity in relation to the pre-milled channel was very precise, indicated by very close values of 743 µm and 739 µm.

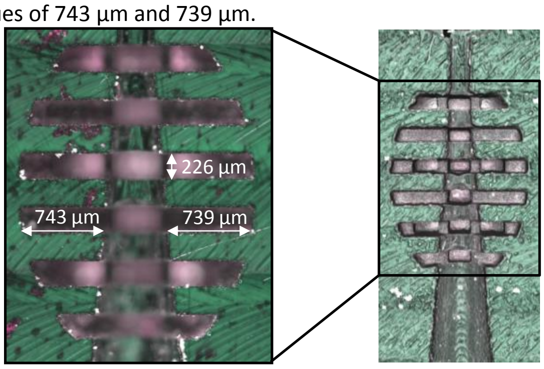

Figure 4. Final produced cavities applying distinct strategies

4. Summary

Total machining time below 27 min as well as total tool electrode frontal wear below 80 µm could be achieved. The cavity with micro structures could be produced on the high grade stainless steel with respect to the requirements, including the exact size of structures (226 µm width) and precise position of cavity on the workpiece. The die-sinking µ-EDM confirmed to be a suitable technology for producing the cavities with micro-structures in hardened steel.

For a future better positioning of the cavity with the micro features on the work piece it is intended to follow two approaches in the future: the implementation of the zero point system to change the electrode between milling and EDM-machine and the implementation of an automation system connecting both machine tools.

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