

Functional Edge Shaping of Micro Bores by Applying Electrochemical Machining

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Abstract

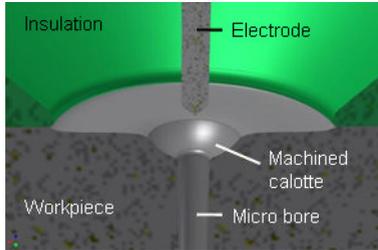
Micro bores are used for several high-precision applications, especially in hydraulic systems and fuel injectors. In this case the shape, particularly the edge rounding of the injection spray hole, has a significant influence on the atomization of fluids and therefore also on the combustion process [1]. Usually these micro bores are machined by electrical discharge machining (EDM) [2]. In EDM sharp edges occur due to the process characteristics and a specific influence on the edge shape is not possible. Thus, a specific and independent adjustment of the edge rounding is required. To produce such a defined edge rounding of bores, an Electrochemical Machining (ECM) process has been investigated. The advantages of this process lie in the possible high localization of the erosion process and high achievable surface quality. The tool which is the cathode has a negative potential and determined by the design of the edge rounding [3]. An experimental set-up was developed in order to perform the investigations. This paper presents the setup and experimental investigations.

1 Introduction

This investigation examines the possibility of applying ECM for rounding the edges of micro bores without influencing the roughness of the bore interior wall. The investigated material was steel and the bore diameters were 100 to 200 microns. Between the workpiece with anodic polarization and the electrode with cathodic polarization, caused by charge transport and continuous electrolyte flushing, anodic dissolution takes place on the workpiece surface. Based on the process principle a calotte shape will be machined. The machining process was developed and realized at Fraunhofer IWU in cooperation with Chemnitz University of Technology. An experimental device was designed and realized for performing systematic experiments for a feasibility analysis.

2 Development of the experimental set-up

A strongly localized removal area must be achieved because of the geometric dimensions of the micro bore and the edge rounding. Therefore, a minimal working gap of 30-50 microns and a low electrolyte conductivity of 20 up to 70 mS/cm were chosen. Furthermore, a tool electrode diameter of 100 microns was selected. Figure 2 depicts the process arrangement and the resulting removal geometry.



into the flushing chamber from underneath.

Figure 2: Scheme of the process arrangement

The workpiece is partially shielded from the electrolyte by an insulating cover. The electrode is positioned coaxially over the micro bore. Conductive materials realize the electrical contact from the clamping system to the workpiece as well as to the electrode.

3 Design of Experiments

The experiments were performed using a prototype ECM system at Fraunhofer IWU. The experimental setup is shown in figure 3. A Tungsten Carbide electrode with a tip angle of 120 degree was used. The electrode diameter was 100 μm . Hardened 18CrNi8 steel was applied

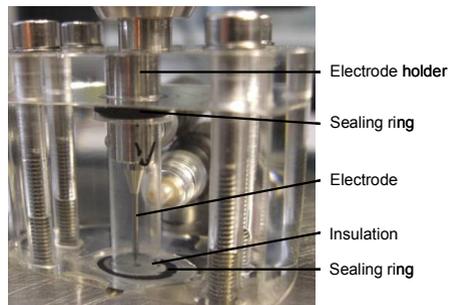


Figure 3: Flushing chamber

bore was machined by EDM up to a diameter of approximately 120 μm . The flushing chamber consisted of acrylic glass to ensure visual process control. In order to verify the influence of the process parameters on the removal process different experiments were executed. The parameters of conductivity and process time were changed within appropriate values. Table 1 summarizes the parameters for the conducted

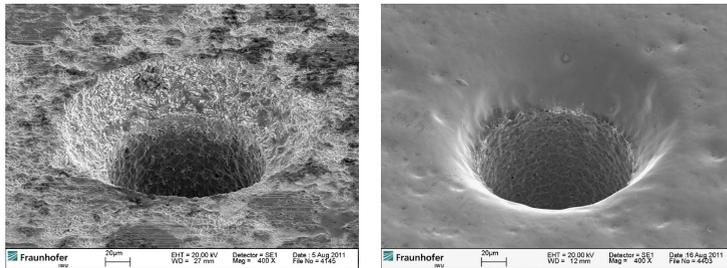
experiments. To quantify the removal the mean current efficiencies were evaluated. Therefore, the removed masses were determined by differential measurement of the workpiece weight before and after processing by using a Sartorius micro balance ME614S. To analyze the surface parameter Sa corresponding to DIN EN ISO 25178-2, a confocal microscope by the Institute of Applied Optics, University of Stuttgart, was used.

Table1: Experimental parameters

Symbol	Parameter	Values for finishing
	<i>Electrolyte</i>	<i>Sodium Nitrate</i>
σ	<i>Electric conductivity</i>	<i>20 and 70 mS/cm \pm 0.5 mS/cm</i>
p	<i>Flushing chamber pressure</i>	<i>Normal pressure</i>
a	<i>Working distance (at beginning)</i>	<i>40 μm</i>
U	<i>Working gap voltage</i>	<i>20 V</i>
v	<i>Feed rate</i>	<i>0 mm/min</i>
t	<i>Process time</i>	<i>0.5 s, 1 s, 2.5 s, 5 s, 7 s</i>

4 Experimental results

An EC processing to form a calotte-shaped geometry can be successfully applied, removing the edge of the workpiece bore.



a) $\sigma = 20$ mS/cm, $U = 12$ V, $t = 5$ s

b) $\sigma = 70$ mS/cm, $U = 20$ V, $t = 7$ s

Figure 4: SEM images of the machining results

The expected calotte geometry is clearly visible. It could be observed that the surface of the bore interior wall was not affected by the EC process. Figure 4 a) shows a highly localized removal of the bore edge, which was realized by setting process parameters to lower voltage levels. The outer diameter is 160 microns, the edge rounding depth is 20 microns and the roughness Sa is 1.2 microns. As shown in Figure 4 b), an increase of voltage and conductivity leads to a flat removal around the micro bore. Here, an outer diameter of 220 microns was generated with an edge

rounding depth of 43 microns. The resulting roughness of the rounding Sa is 0.5 microns. In order to quantify the process figure 5 shows the removal mass relative to the electric charge transport for different experiments.

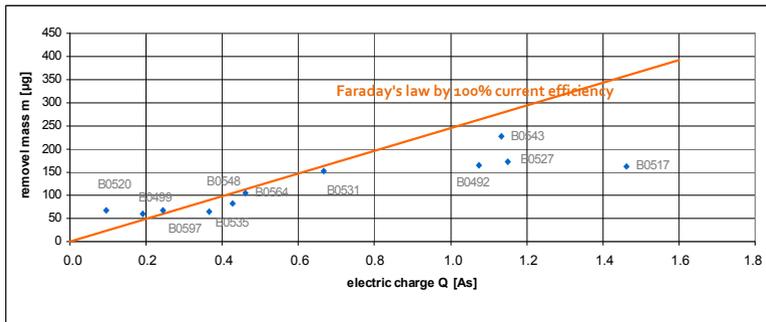


Figure 5: Removal mass of different experiments, depending on electric charge transport.

As a reference, the solid line depicts Faraday's law relative to the specific workpiece material and a current efficiency of 100%. For small amounts of electric charge, the comparison shows accordance with Faraday's law. Therefore, the current efficiency rises up to 100% for small amounts of electric charge. Larger amounts of electric charge do not coincide with the reference line of Faraday's law. That means only a certain amount of electric charge is used for the removal. This is justified by the increasing working gap during machining. This results in a decrease in current efficiency down to 45%.

5 Summary

The experiments show that a localized removal of the edge of a micro bore is possible by using Electrochemical Machining. It can be seen that a defined edge rounding could be placed at the bore. Furthermore it could be proved that the intended structure of the bore interior wall had not been influenced by the process.

Acknowledgment

The joint project is funded by the European Union and the Free State of Saxony.



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