Generating Micro Geometries with Air assisted Jet Electrochemical Machining

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Abstract

In Jet Electrochemical Machining (Jet-ECM), the electrolytic current between the anodic work piece and the cathodic nozzle is supplied via an electrolyte jet which is ejected from a nozzle. The main advantage compared to other EC processes is the restriction of the electrolytic current to a limited area by the jet. The dissolution rate and the machining position can easily be controlled by setting the electric current and the nozzle position. Higher dissolution rates compared to pulsed ECM are possible, because continuous direct current is applied.

In this study the property of using an additional jet of compressed air to assist the procedure is presented. The additional jet of compressed air removes the electrolyte film enclosing the metallic nozzle, which is caused by surface tension. Thereby localisation is enhanced and working gaps of about 100 µm (distance between work piece and nozzle) can be used.

Furthermore a FEM model was developed to simulate selected processing results.

1 Experimental Setup

The typical experimental setup for Jet-ECM is known from literature [1, 2]. The general machining conditions are shown in **table 1**. In this study a sodium chloride (NaCl) aqueous solution with a concentration of 20 wt.% was used as the electrolyte. Commercial full metal stainless steel nozzles were applied for machining of different metals. Constant current or constant voltage is provided and controlled from a power supply with ±1 A maximum output current and ±56 V maximum output voltage. All positioning actions of the X, Y and Z axes are CAM controlled by a personal computer.

Table1: General experimental conditions

Nozzle diameter [µm]	100
Electrolyte	NaCl
Concentration [wt.%]	20
Electrolyte mean velocity [m/s]	20
Working gap [µm]	100

The effect of using an additional jet of compressed air is illustrated in **figure 1**. The left picture shows, that after starting the pump, an electrolyte film, which is caused by surface tension, encloses the metallic nozzle. The film delocalises the current density between nozzle and work piece. The right picture shows the air jet removing the electrolyte film. A free closed electrolyte jet is achieved which increases the localisation. Working gaps of about 100 µm can be used. An exemplary result of machining an array of pits without and with air assistance is demonstrated in **figure 2**.

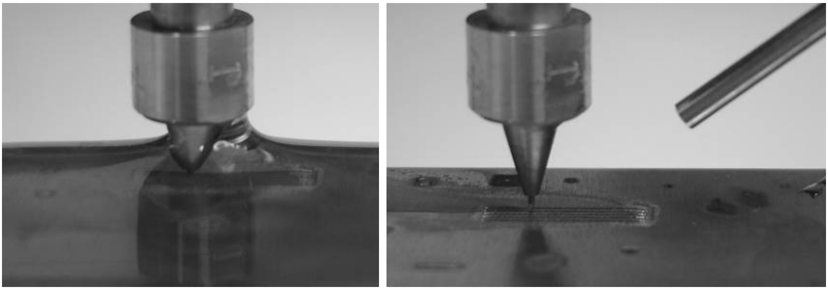


Figure 1**:** left: photo of electrolyte nozzle enclosed by the film; right: photo of electrolyte nozzle with additional nozzle for compressed air removing the film [3]

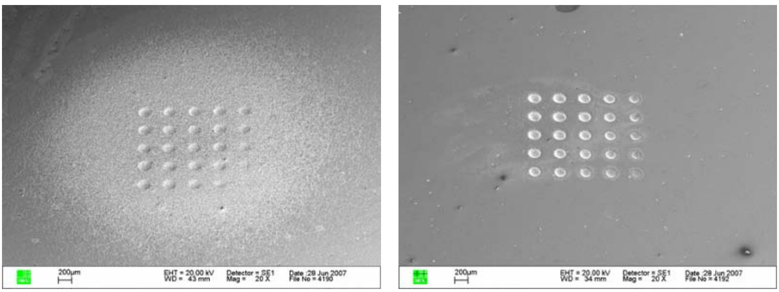


Figure 2**:** left: pit array machined without air assistance; right: pit array machined with air assistance, (pits with different machining parameters)

The pits were machined with different voltages within several times. In the left picture an high stray removal is obvious. Under same experimental conditions by help of the free closed electrolyte jet in the right image of **figure 2** no stray removal is observed.

2 Machining micro geometries

Examples for machining of steel 1.4718 with a free closed electrolyte jet are shown in **figure 3**. The bows in the left picture were processed 1, 2 and 3 times starting from the left one. Various depths of the grooves of 35 µm (1 time), 65 µm (2 times) and 90 µm (3 times) were achieved. Especially the localisation of the dissolution process is obvious. With 100 µm nozzle diameter the machined area has a diameter of about 200 µm. The right picture of **figure 3** shows a part of an array of pits. Every pit was machined for 0,5 s with an average current density of about 150 A/cm². A depth of 45 µm was achieved. The localisation of the dissolution process is apparent again.

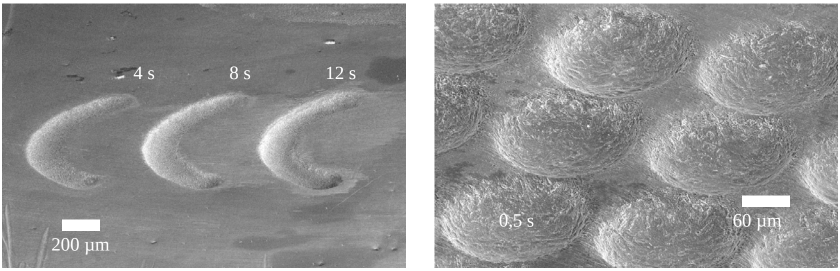
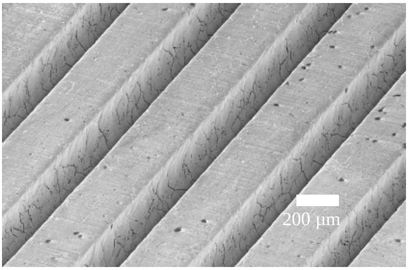


Figure 3: left: SEM of machined bows in steel 1.4718; right: SEM of within 0,5 s machined pits in steel 1.4718

The potential of air assisted Jet-ECM for machining of large area and deep micro geometries is demonstrated in **figure 4** with an array of five grooves generated in Nimonic80A, a Ni based alloy. Every groove is 10.000 µm long, 200 µm wide and 300 µm deep. The nozzle was moved twelve times with a velocity of 150 µm/s over the geometry. A total machining time for the five grooves of about 90 min was needed. Remarkable are the sharp edges and scarp flanks of the grooves, which are not typical for electrochemical processes. Typical for Ni alloys is the etching of grain boundaries apparent in the right picture.

One approach to reduce the processing time is to apply multiple nozzles [4].



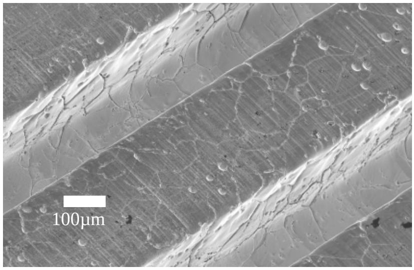
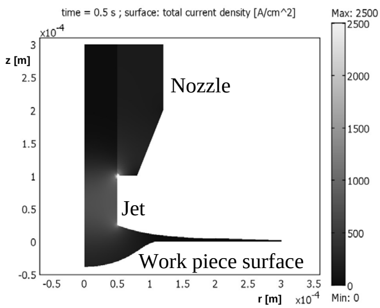


Figure 4: left and right: SEM images of machined grooves in Nimonic80A

3 FEM Simulation

The commercial software COMSOL Multiphysics™ is used to simulate the experimental results shown in **figure 3** right with a pseudo 3-D model. The geometry of the arrangement of jet, nozzle and work piece was taken from literature [5]. All electrostatic parameters, e. g. conductivity and potential are the same as in the experiments. To describe the dissolution process corresponding to Faraday's law a displacement of the mesh in normal direction caused by current density was defined [6]. The current efficiency as a function of current density was taken from experimental data [7]. **Figure 5** left shows the simulated geometry at time 0,5 s with a surface plot of the total current density and deformed shape of the work piece. At time 0 s the work piece surface was the abscissa. For a better comparison with the machining results the coordinates of the deformed shape were exported and plotted with a pit profile measured by optical methods in **figure 5** right.



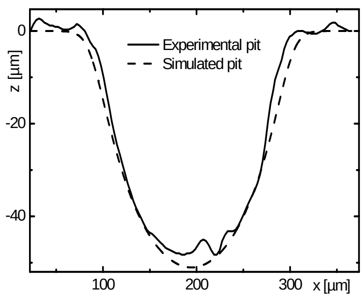


Figure 5: left: simulation arrangement; right: measured and simulated pit profile

Simulated and machined pits show a similar geometry and in both cases the pit is about 50 µm deep. In 10 µm depth the width of the simulated pit is only about 20 µm larger than the width of the machined pit.

4 Conclusions

In this study the potential of air assisted Jet-ECM for the machining of micro geometries is demonstrated. Especially a high dissolution ratio caused by direct current with high current densities and a good localisation of the process were shown. The property of using an additional jet of compressed air to realise a free closed electrolyte jet was presented.

Additional a FEM model of the dissolution process was developed including experimental parameters and data taken from literature. The model is used to simulate the geometry of machined pits. Experimental and simulated pits show a good coincidence. That means Jet-ECM of pits can be described with a very simple model which only consists of electrostatics and mesh displacement.

References:

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