Jet Electrochemical Machining of Particle Reinforced Aluminum Matrix Composites with Different Neutral Electrolytes

M Hackert-Oschätzchen, N Lehnert, A Martin and A Schubert

Technische Universität Chemnitz, Professorship Micromanufacturing Technology, Chemnitz, Germany

E-mail: `norbert.lehnert@mb.tu-chemnitz.de`

Abstract. Conventional mechanical machining of particle reinforced aluminum matrix composites (AMCs) is challenging because the hard ceramic particles in the soft aluminum matrix lead to an increased tool wear. Furthermore, the mechanical and thermal impact during conventional machining affects the microstructure of the AMCs. Electrochemical machining (ECM) is an alternative method to machine AMCs. Based on anodic dissolution, ECM has a slight influence on the work piece material structure and is independent of material strength and hardness. So the microstructure of the work piece remains unaffected. One method of ECM is electrochemical machining with continuous electrolytic free jet (Jet-ECM). Hereby the electrochemical removal is localized by the geometry of the electrolyte jet. By moving the electrolyte jet micro-structures and microgeometries can be generated quickly and flexibly in metallic parts [1]. Another advantage of Jet-ECM is the low consumption of electrolyte which allows an easy and inexpensive change of electrolyte for investigations with different types of electrolyte. In this study AMCs reinforced with different amounts of SiC-particles are machined with two pH-neutral electrolytes using Jet-ECM. The results provide information about the suitability of the selected electrolytes for the machining of AMCs. In addition, the influence of the particle content on the electrochemical removal result will be evaluated.

1. Introduction

The requirements concerning material properties are rising steadily, especially for safety-related components. If a material should have a low density to reduce mass, but also should have a high stiffness, conventional materials like metals, ceramics or polymers, can hardly meet the demands. Composite materials, which are a combination of two or more physically and chemically different materials, can fulfill such requirements. The different materials exist as separated phases in the composite. The major phase is the matrix material and the minor phase is the reinforcement, which is shown schematically in figure 1 for a particle reinforced metal matrix composite. The properties of the composite material, such as E-modulus or thermal expansion, are defined by the used materials and their proportions. So the new material may have properties similar to steel, though with lower density, which leads to a mass reduction. Such materials are used e.g. in aeronautics and automotive parts [2].

In the Collaborative Research Center SFB 692 HALS at the Technische Universität Chemnitz several academic institutions work together in the investigation of aluminum matrix composites
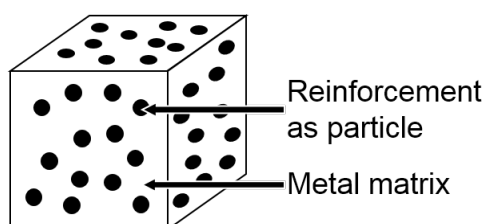
Figure 1. Scheme of the microstructure of a particle reinforced metal [3]

(AMCs). One main task is the finishing machining of AMCs by electrochemical machining (ECM).

In this study jet electrochemical machining (Jet-ECM) of AMCs using neutral electrolytes is investigated. The AMCs are the aluminum alloy EN AW 2017 reinforced with SiC-particles with diameters less or equal to 1 μm. The applied electrolytes are aqueous solutions of $NaNO_3$ or NaCl with a conductivity of approximately 185 $\frac{mS}{cm}$ at a temperature of 25 ℃.

2. Jet Electrochemical Machining

Electrochemical machining is based on the anodic dissolution of work piece material through electric charge transport. The dissolution takes place at the interface between the work piece surface and the electrolyte. The special characteristic of Jet-ECM is the supply of fresh electrolyte through a micro nozzle with a mean jet velocity of approximately 20 $\frac{m}{s}$ [1, 3, 4]. Figure 2 shows the principle of Jet-ECM.
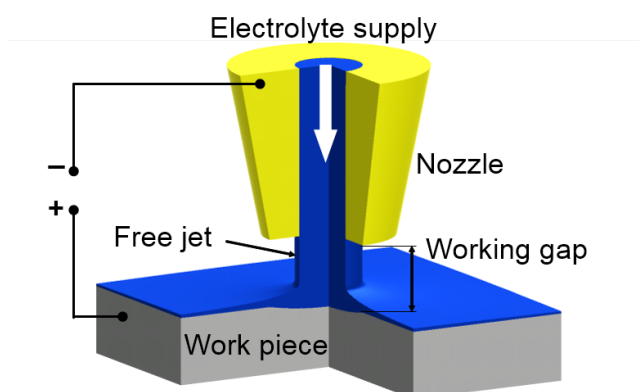

Figure 2. Principle of Jet-ECM [1, 3, 4]

The electrolyte is ejected vertically towards the work piece surface. Due to the high velocity, a closed free jet is formed in the surrounding atmospheric air. The current density is locally confined by the electrolyte jet leading to a highly localized machining area [1, 4].

In the jet current densities up to 2000 $\frac{A}{cm^2}$ can be realized [5]. As a result, excellent surface qualities can be achieved. The high velocity of the electrolyte jet leads to a very good supply with fresh electrolyte [1, 4].

The experiments of Jet-ECM of particle reinforced AMCs with different neutral electrolytes were performed on a modular prototype system. Figure 3 shows a scheme of the setup.

The experimental setup is mounted on a table and a portal made of granite to guarantee the required mechanical and thermal stiffness. The relative movement between nozzle and work piece is carried out by a three-axis positioning system. A pulsation-free pump transports the electrolyte to the nozzle. The electrolyte is ejected in z direction towards the work piece. Used electrolyte is collected in a disposal tank. A generator system supplies electric voltage between the nozzle and the work piece, providing the process current. A personal computer serves as control system for all electrical and kinematic operations of the system [1, 3, 4].
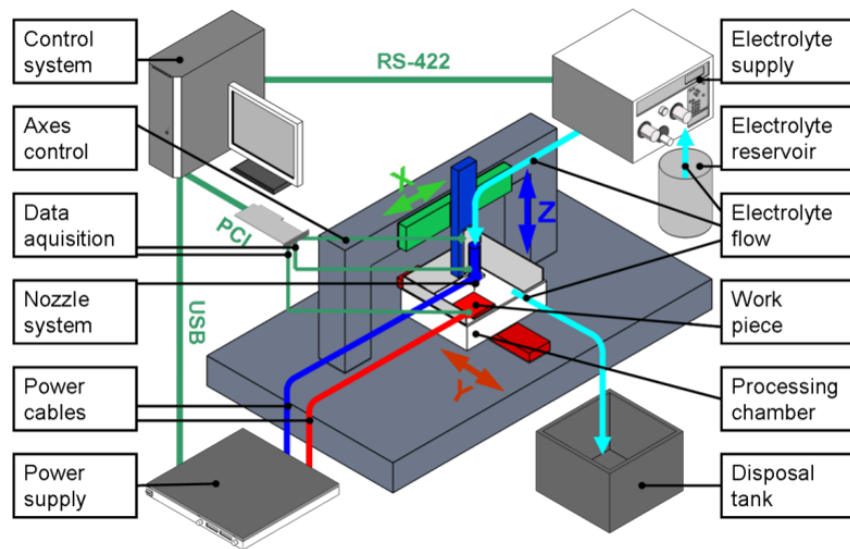
Figure 3. Scheme of the experimental setup of Jet-ECM [1, 4]

3. Experimental Parameters

The work piece materials are AMCs with a matrix of EN AW 2017 and a reinforcement content of 5% or else 10% SiC-particles. The particles have a diameter of less or equal 1 µm. Both AMCs were produced within the Collaborative Research Center SFB 692 HALS. As mentioned above, two pH-neutral electrolytes were used to perform the experiments. For comparability the aqueous solutions of $NaNO_3$ or NaCl have the same electric conductivity of approximately 185 $\frac{mS}{cm}$ at a temperature of 25 °C. The used nozzle has an inner diameter of 100 µm.

For the experiments a standardized machining strategy, point machining, was used. Point machining generates calottes on the work piece surface. Thereby the machining time and the applied voltage were varied. Table 1 summarizes selected parameters of the experiments.

Table 1. Selected experimental parameters

Parameter	Values
Work piece materials	EN AW 2017 + 5% SiC-particles
	EN AW 2017 + 10% SiC-particles
Electrolytes	$NaNO_3$, NaCl
Electrolyte conductivity	185 $\frac{mS}{cm}$
Nozzle diameter	100 µm
Working gap	100 µm
Machining time for point machining	0.5 s, 1 s, 1.5 s, 2 s
Applied voltage	10 V, 15 V, 20 V, 25 V

4. Experimental Results

The generated geometries were evaluated qualitatively by scanning electron microscopy and quantitatively by confocal microscopy. Figure 4 shows SEM images of calottes generated on EN AW 2017 + 10% SiC at 20 V and 2 s machining time.
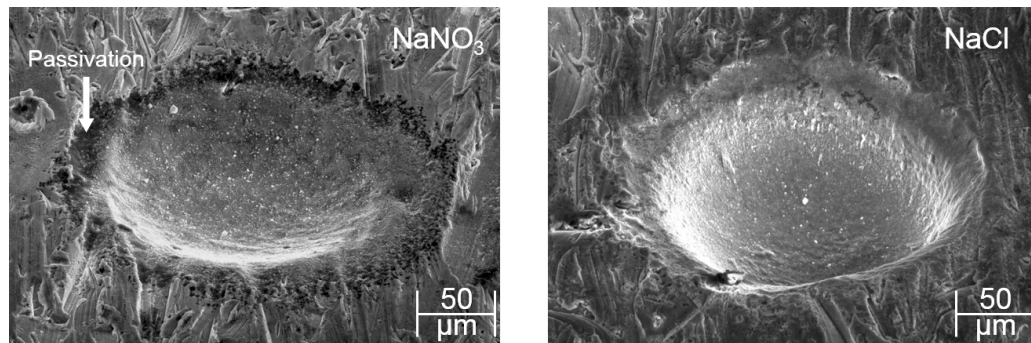
Figure 4. SEM images of calottes on EN AW 2017 + 10% SiC-particles machined with 20 V, 2 s and aqueous electrolyte of $NaNO_3$ and NaCl

The images show calottes generated by applying $NaNO_3$ electrolyte (left) and NaCl electrolyte (right). Further machining parameters are similar. It can be seen that in both cases the machined surface is much smoother than the initial work piece surface. At the edge of the calotte machined with $NaNO_3$, a region can be spotted that appears black in the SEM image. This region indicates passivation effects [3]. The SEM image of the calotte generated by applying NaCl electrolyte indicates no passivation effects. The edge appears more rounded than with $NaNO_3$. The calotte generated with NaCl appears deeper than the one generated by applying $NaNO_3$ electrolyte. This observation is confirmed by confocal microscopy. Figure 5 shows section views of calottes according to the SEM-images in figure 4.
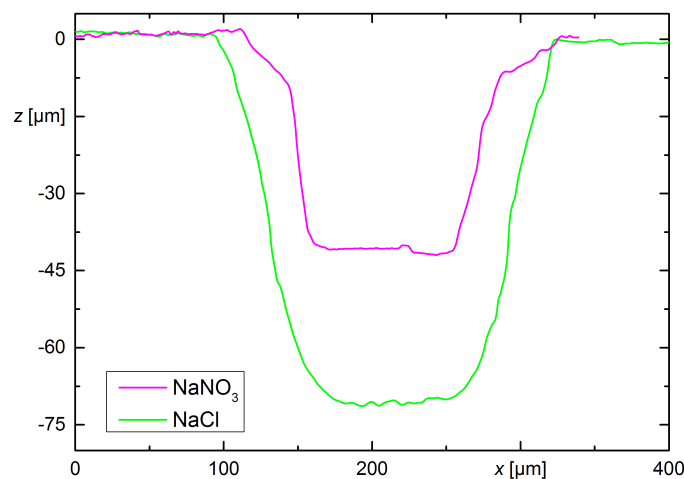

Figure 5. Section views of calottes on EN AW 2017 + 10% SiC-particles machined with 20 V, 2 s and aqueous electrolyte of $NaNO_3$ and NaCl

Obviously, the calotte generated by applying NaCl is significantly wider and deeper than the other calotte, which implies that the AMC dissolves much faster by using NaCl electrolyte. Figure 6 shows diagrams of diameters d and depths z of the calottes on EN AW 2017 + 10% SiC-particles as a function of time with variation of the applied voltage for each electrolyte.

In both cases it can be seen that diameter and depth increase with machining time and voltage. The calottes have equal diameters of approximately twice the nozzle diameter,
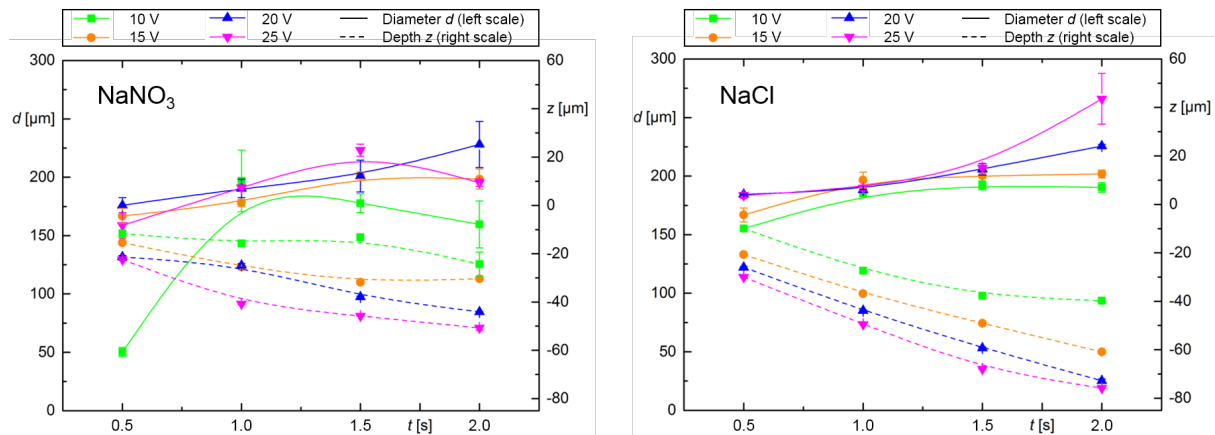
Figure 6. Diameter d and depth z of calottes on EN AW 2017 + 10% SiC-particles machined with aqueous electrolyte of NaNO$_3$ and NaCl as a function of machining time t and applied voltage

regardless of the used electrolyte. This is a result of the high localization of the current density in Jet-ECM. The function of the diameter of the calottes machined applying NaNO$_3$ electrolyte at 10 V is significantly different. This implies that, by using NaNO$_3$ as electrolyte, a voltage of 10 V is too low to establish a reproducible dissolution process. As mentioned above, the calottes machined with the NaCl electrolyte are deeper for most of the experiments. It can be estimated that the calottes machined using NaCl are up to twice as deep as the calottes machined using NaNO$_3$. Figure 7 shows diagrams similar to figure 6 for the calottes on EN AW 2017 + 5% SiC-particles.
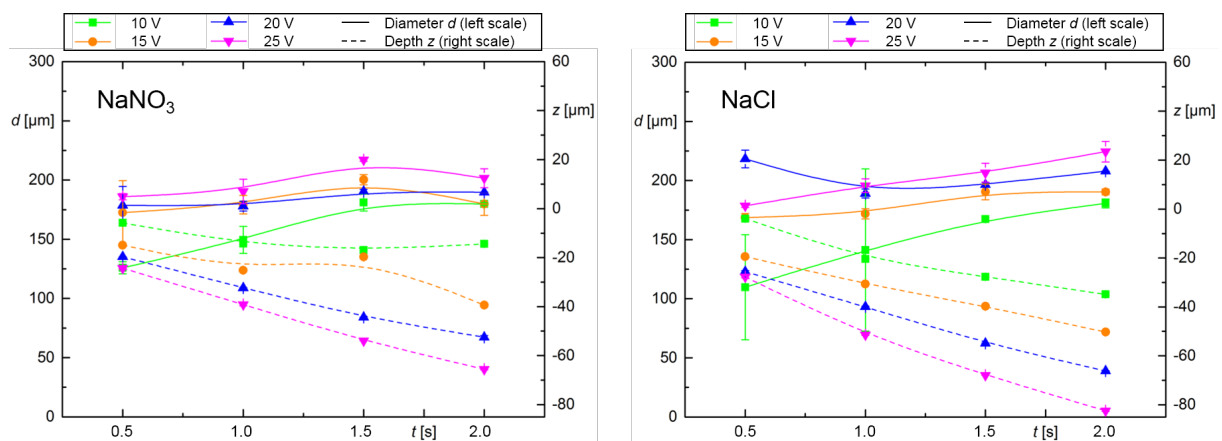

Figure 7. Diameter d and depth z of calottes on EN AW 2017 + 5% SiC-particles machined with aqueous electrolyte of NaNO$_3$ and NaCl as a function of machining time t and applied voltage

Similar to the AMC with 10% SiC-particles, diameter and depth increase with machining time and voltage. Also, the calottes machined by applying NaCl are deeper than the calottes machined by applying NaNO$_3$ in most cases. Comparing the results of the two work piece

5

materials, as shown in figures 6 and 7, the different amounts of SiC-particles have no significant influence on the dimensions of the generated calottes. This can be attributed to the small difference of their percentage.

5. Conclusion

Jet electrochemical machining of particle reinforced aluminum matrix composites with different neutral electrolytes was evaluated in this study. The suitability of aqueous electrolyte of $NaNO_3$ and NaCl for machining AMCs and the machining results were analyzed.

Generally speaking, Jet-ECM of the investigated AMCs was applied successfully using the two pH-neutral electrolytes. It could be shown, that the aqueous electrolytes of $NaNO_3$ and NaCl cause different electrochemical dissolution characteristics. While the diameters of the calottes created with both electrolytes are similar, the usage of NaCl electrolyte results in significantly deeper calottes for machining times of about 1.5 to 2 seconds. By using $NaNO_3$ passivation effects can be spotted. To achieve reproducible dissolution behavior when applying $NaNO_3$ electrolyte the voltage should be adjusted above 10 V. The slight variation of the amount of SiC-particles, from 10% to 5%, has no significant influence on the machining results.

Acknowledgment

References
[1] Hackert-Oschätzchen M, Meichsner G, Zinecker M, Martin A and Schubert, A 2012 *Precis. Eng.* **36** **4** 612–9
[2] Chawla K K 2012 *Composite Materials 3rd ed.* (New York: Springer)
[3] Hackert-Oschätzchen M, Morgenstern R, Lehnert N, Martin A, Lampke T and Schubert A 2015 *Proc. of 11th International Symposium on Electrochemical Machining Technology* 35–42
[4] Hackert-Oschätzchen M, Martin A, Meichsner G, Zinecker M and Schubert A 2013 *Precis. Eng.* **37** **3** 621–34
[5] Schubert A, Hackert-Oschätzchen M, Meichsner G, Zinecker M and Martin A 2011 *Proc. of 7th International Symposium on Electrochemical Machining Technology* 47–54.