euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

# Challenge of machining aluminium matrix composites reinforced by diamonds

Andreas Schubert[1,2], Henning Zeidler[1], Sebastian Flemmig[1], Michael Penzel[1], Maik Krönert[1], Gunnar Meichsner[2], Shai Essel[3]

[1]*Professorship Micromanufacturing Technology, Technische Universität Chemnitz, 09107 Chemnitz, Germany*
[2]*Fraunhofer Institute for Machine Tools and Forming Technology, 09126 Chemnitz, Germany*
[3]*Israel Institute of Metals, Technion, Haifa, Israel*

*henning.zeidler@mb.tu-chemnitz.de*

**Abstract**
To increase the efficiency of heat transfer and cooling systems, high thermally conductive materials have to be developed. Using Aluminium reinforced by Diamond particles, thermal conductivity and heat dissipation can be enhanced in correspondence to particle size. Due to the high hardness of diamond the machinability decreases. A cutting machining process is not feasible because of the high tool wear. In this study two possible ablating techniques, Pulsed Electrochemical Machining (PECM) and Micro Electro Discharge Machining (µEDM) are assessed. It is shown that with both methods machining and shaping of AMCs, reinforced by monocrystalline diamonds, is possible. Due to the chemical stability of the diamond particles only the base material of Aluminium has been electrochemical machined. Similar to PECM, and also for µEDM, ablating is a selective machining process, but here an approach for further ablating possibilities is given. The achieved surface roughness is dependant on the particle size of the Diamond.

Keywords: Monocrystalline Diamond, AMC, machining, Micro-µEDM, PECM, heat transport

## 1. Introduction

The increasing power density of electronic devices and components requires the development of new cooling methods and systems by which large heat fluxes can be dissipated. One method is to transport the heat from a heat source to the cooling system. To increase the efficiency of such heat transfer and cooling systems, high thermally conductive materials have to be developed. At present, a commonly used material for heat transport applications is Aluminium. Aluminium has high mechanical stability, low weight but also a medium high heat transfer coefficient of 180 W/(m·K) (for A356). Monocrystalline Diamond with more than ten times higher thermal conductivity than Aluminium could offer an additional solution for thermal transport applications. By combining Aluminium and monocrystalline Diamonds to composite materials, the positive properties of each material can be used. Therefore, an Aluminium Matrix composite (AMC) reinforced with monocrystalline Diamond particles was created.

## 2. Theoretical Basics

The materials used are Aluminium-alloy A356 and monocrystalline Diamond particles with a diameter of approximately 100 µm. The percentage of Diamonds within the Aluminium is about 40 vol%. It is known that with rising grain size of Diamond the thermal conductivity of the AMC is increasing [1]. However, also the machining becomes more challenging with such big particles [2], i.e. cutting processes are not feasible due to the high tool wear. For machining the samples, the two non-conventional machining processes precise electro chemical machining (PECM) and micro electro discharge machining (µEDM) are assessed.

### *2.1. Pulsed Electrochemical Machining*

Pulsed Electrochemical Machining (PECM) is the further development of an ECM process and operates with small working gaps between the workpiece and tool electrode. During machining, the gap distance in the feed direction can be smaller than 10 µm. In PECM, a pulsed direct current and an oscillating tool electrode are used. With this it is possible to achieve the small working gap, which increases the precision of machining due to higher localisation of the current density. Figure 1 shows the process phases of the PECM process in a schematic. [3]

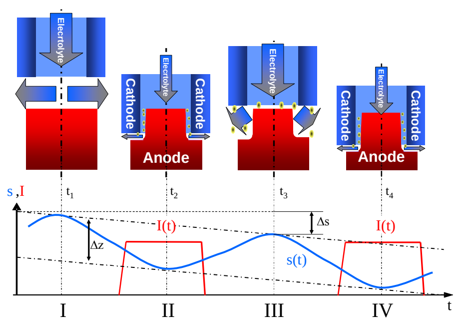


**Figure 1**: Principle and phases of Pulsed Electrochemical Machining [3]

### *2.2. Micro Electro Discharge Machining*

The process of Micro Electro Discharge Machining (µEDM) is based on ablation of material by melting and evaporation. Electric discharge occurs between the tool electrode and workpiece. Tool and work piece are separated by a dielectric fluid. To both electrodes a voltage is attached and when the breakdown voltage of the fluid is reached, discharge takes place and a plasma channel forms. The temperatures in the base of the plasma channel can reach T ≥ 10000 K. [4] Due to the process principle of non-contact ablating material by melting and evaporating, caused by electric discharges, µEDM is independent of material hardness, brittleness or toughness. [5]

### 3. Experimental setup

The Experiments were performed with a µEDM machine Sarix SX100 and a PECM system PEM-Center 8000. The machining systems used are shown in Figure 2.

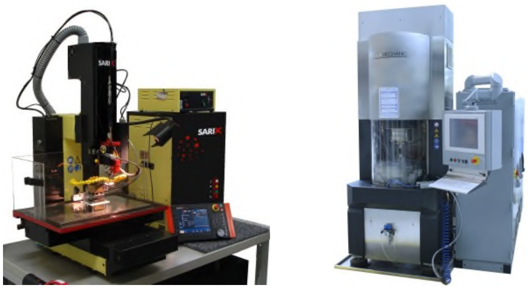

**Figure 2**: Sarix SX100 (left) and PEMcenter 8000 (right)

During EDM, synthetic dielectric HEDMA-Oil and an electrolyte for PECM $NaNO_3$ are used.

The machined surfaces are analysed by 3D laser scanning microscope Keyence VK – 9700.

### 4. Results

Results shows that machining an AMC reinforced with monocrystalline Diamond particles is possible in general and material removal of both methods behaves similarly. Machined surfaces are shown in Figure 3. Monocrystalline Diamond is not electrically conductive and has a high chemical stability, so it cannot be dissolved by PECM. Due to its high thermal conductivity, its removal in µEDM is very small, too. Both processing methods are removing the Aluminium base material, but using different physical principles.

During PECM, just the electrical conductive Aluminium is machined. By removing the Aluminium matrix, the non-conductive diamonds will fall out of the surface layer.
The continuous electrolyte flushing removes the fallen out diamonds from the machining zone. Figure 3 (left) shows a PECM generated surface. Because of the different dissolution behavior of the Aluminium alloy components and the removal of the diamonds an uneven craggy surface is produced.

The machining result of the eroded part looks similar to the electrochemical processed one. During µEDM, the Aluminium is molten and removed, due to the thermal impact of the discharge in the plasma channel, while Diamond, being a very good thermal conductor, dissipates the heat into the Aluminium. The Diamond particles protrude from the Aluminium surface until enough base material is ablated and they will fall out. This is represented by the crater formation, seen in Figure 3 right. Hence, hardly any removal of Diamond takes place.

One difference can be seen in the adjusted orientation of the diamond particles at the surface. In comparison with the PECM surface, no peak of the diamond particles is noticeable; they look smooth and nearly parallel to the surface.

This could be explained with an indirect machining of the diamond. When a discharge takes place in the Aluminium next to a Diamond particle, the plasma channel spreads out and the thermal energy is conducted into the diamond. Due to the high temperatures inside the plasma channel, of more than 10000 K, the enclosed part of the diamond will be sublimated.

For both machining methods a surface roughness of about Rz = 100 µm are achieved. Due to the diamond particle size of approximately 100 µm and the selective ablating process, a lower surface roughness could only be achievable by either smaller Diamond particles, or a possibility of machining the monocrystalline diamond particles.

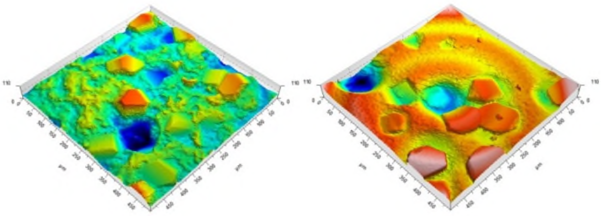

**Figure 3**: PECM-surface (left) and µEDM-surface of machined Aluminium with Diamond

For machining and shaping of AMCs reinforced by monocrystalline diamonds, both machining technologies, PECM and µEDM, are feasible but not able to machine the Diamond particles directly. PECM and µEDM dissolve the Aluminium base material which leads to ablating of the AMCs.

Further investigations have to be carried out to achieve a possibility of an ablating mechanism of Diamond particles to create smoother surfaces.

**Acknowledgements:**
This approach is investigated in the ongoing project THERMACO (Smart Thermal conductive Al MMCs by casting), which receives funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement number 608978.

**References**
[1] K. Chu, C. Jia, X. Liang, H. Chen, W. Gao, and H. Guo, “Modeling the thermal conductivity of diamond reinforced aluminium matrix composites with inhomogeneous interfacial conductance,” *Mater. Des.*, vol. 30, no. 10, pp. 4311–4316, Dec. 2009.
[2] I. Ciftci, M. Turker, and U. Seker, “CBN cutting tool wear during machining of particulate reinforced MMCs,” *Wear*, vol. 257, no. 9–10, pp. 1041–1046, Nov. 2004.
[3] G. Meichsner, L. Boenig, M. Hackert-Oschätzchen, M. Krönert, T. Petzold, J. Edelmann, and A. Schubert, “Determination of the gas generation during precise electrochemical machining,” in *Proceedings of the 10th International Symposium on Electrochemical Machining Technology*, D. Bähre and A. Rebschläger, Eds. 2014, pp. 63–75.
[4] A. Schubert, H. Zeidler, N. Wolf, and M. Hackert, “Micro Electro Discharge Machining of Electrically Nonconductive Ceramics,” in *AIP Conference Proceedings*, 2011, vol. 1308, no. May, pp. 1303–1308.
[5] H. Zeidler, A. Schubert, N. Wolf, M. Hackert-Oschätzchen, and J. Schneider, “Ultrasonic-Assisted Micro-EDM of Deep Bores : Process and Discharge Analysis,” in *Proceedings of the 12th euspen International Conference*, 2012, no. June, pp. 1–4.