# Jet-Electrochemical machining of selective laser melted aluminum and steel alloys for micro injection moulds

Andreas Schubert[1,2], Henning Zeidler[1], André Martin[1], Matthias Hackert-Oschätzchen[1], Karolien Kempen[3], Jean-Pierre Kruth[3]
[1]*Professorship Micromanufacturing Technology, Faculty of Mechanical Engineering, Technische Universität Chemnitz, 09107 Chemnitz, Germany*
[2]*Fraunhofer Institute for Machine Tools and Forming Technology, 09126 Chemnitz, Germany*
[3]*University of Leuven (KU Leuven), Department of Mechanical Engineering, Celestijnenlaan 300, 3001 Leuven, Belgium*
*henning.zeidler@mb.tu-chemnitz.de*

## Abstract

For a flexible and resource efficient generation of moulds for micro-injection moulding, additive manufacturing processes such as Selective Laser Melting are used. Electrochemical machining (ECM) is a promising technique for the final shaping of the mould and for creation of the injection cavity with required precision, since ECM is independent of material hardness and ductility [1]. The latter property is important concerning SLM produced moulds, which are often harder and stronger than cast moulds [2].

In this study, electrochemical machining of two SLM materials, AlSi10Mg Aluminium alloy and 18Ni-300 Nickel-based maraging tool steel, is analysed. A unique process applying a continuous electrolytic free jet (Jet-ECM) is used that offers the possibility to generate micro-structures by controlling the nozzle movement and the current flow [3].

## 1. Introduction

The basic principle of electrochemical machining is the anodic dissolution of work piece material at the interface between the work piece surface and the electrolyte through electric charge transport. The special characteristic of Jet-ECM is the supply of electrolyte through a micro nozzle at a mean jet velocity of approximately 20 m/s, which leads to the formation of a closed jet as shown in Figure 1 [1,3]. The result is a localised machining area, because the current density is locally confined by the jet.

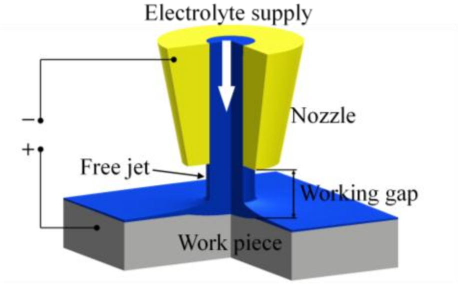


***Figure 1**: Scheme of Jet-ECM [3]*

Extremely high current densities of up to 1000 $A/cm^2$ in the jet can be realised [1,3]. The high velocity of the impinging jet leads to a very good electrolyte supply. Hence, there is no need for interrupting the process for flushing phases, which results in high local removal rates.

The applied sample specimens were manufactured by Selective Laser Melting (SLM), an Additive Manufacturing technique in which a part is built up in a layer-by-layer manner by melting the top layer of a powder bed according to sliced 3D CAD data.

By using a high-intensity laser beam, metal powder particles are completely melted and fused together to obtain almost fully dense parts. Successive layers of metal powder particles are melted and consolidated on top of each other resulting in near-net shaped parts. A schematic overview of the SLM process is illustrated in Figure 2.

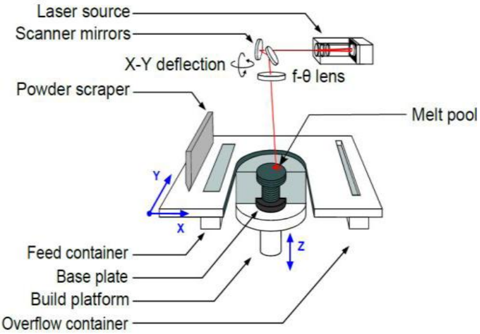


***Figure 2**: Schematic overview of the SLM process*

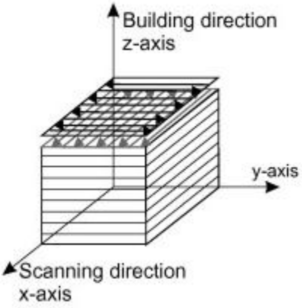


***Figure 3**: Zig-zag scanning strategy with 90° layer rotation*

The AlSi10Mg parts were produced on a modified Concept Laser M1 machine with a laser power of 200 W and scan speed of 1400 mm/s at a spot diameter of 150 µm. The hatch spacing between two consecutive scan tracks is 105 µm. A zig-zag scan pattern was used, with a rotation of 90 ° between every layer. The scan strategy is clarified in Figure 3. In SLM of maraging steel usually applied parameters are a laser power of 100 W, a scan speed of 300 mm/s and a hatch spacing of 112 µm.

## 2. Experimental

The 18Ni-300 steel specimens were obtained from LayerWise NV, Belgium and the AlSi10Mg specimen from Katholieke Universiteit Leuven. Both material samples were delivered as round discs with a height of 1 mm, a diameter of 14.3 mm and two reference edges.

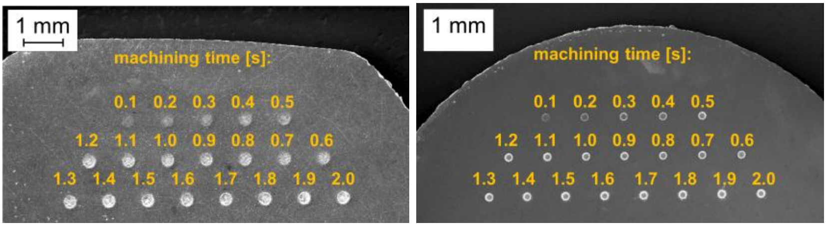
As removal geometries, 20 point erosions were arranged on the sample surfaces. The processing time was varied from 0.1 s to 2.0 s. The applied parameters are depicted in table 1.

***Table 1:** experimental parameters*

| *Symbol* | *Parameter* | *Value* |
|---|---|---|
| | *Electrolyte, mass fraction* | *$NaNO_3$ aqueous solution, 30 %* |
| | *Work piece material* | *18Ni-300 and AlSi10Mg (SLM)* |
| *d* | *Nozzle inner diameter* | *100 µm* |
| *dV/dt* | *Pump delivery rate* | *10 ml/min* |
| *a* | *Initial working gap* | *100 µm* |
| *U* | *Voltage* | *60 V* |
| *t* | *machining time* | *(0.1, 0.2, …, 2.0) s* |

## 3. Results

The top view SEM images in figure 6 show the Jet-ECM results of the analysed alloys with the machining time allocated to each point erosion.

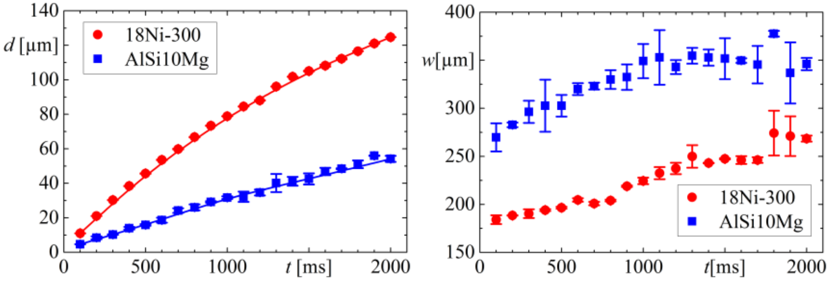


***a)** AlSi10Mg* ***b)** 18Ni-300*

***Figure 8:** SEM overview images of the Jet-ECM results*

The calotte-shaped removals indicate that electrochemical machining was successful in both SLM alloys. The high localisations of the erosions can be derived from the well-defined shape of the indents, where no stray removal is recognisable.

The graphs in figure 10 show the width and depth of the indents, measured with confocal microscopy. The removal depth in both materials increases with an increase in processing time. The declining increase is caused by the growing working gap due to the progressing erosion, which causes an increasing ohmic resistance. In general, the erosion depth in the Aluminium alloy is approximately at 50 % of the erosion depth in the steel specimen.



*a) depth of point erosions* *b) width of point erosions*

***Figure 10:*** *point diagrams of the geometrical dimensions of the point erosions*

In the aluminium alloy the erosions exhibit an obviously wider distribution compared to the steel specimen. Reason for this is the high passivation effect of the steel alloy during ECM with sodium nitrate aqueous electrolyte due to the high iron ratio.

## Acknowledgment

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement number 314055.

## References

[1] Hackert-Oschätzchen, M.; Meichsner, G.; Zinecker, M.; Martin, A.; Schubert,A: Micro Machining with Continuous Electrolytic Free Jet, In: Precision Engineering, Volume 36, Issue 4, October 2012, Pages 612-619, DOI: 10.1016/j.precisioneng.2012.05.003

[2] Kempen, K., Yasa, E., Thijs, L., Kruth, J.-P., Van Humbeeck, J.: Microstructure and mechanical properties of Selective Laser Melted 18Ni-300 steel. In: Physics Proceedia Volume 12; Issue 1, April 2011, Pages 255-263

[3] Hackert-Oschätzchen, M.; Martin, A.; Meichsner, G.; Zinecker, M.; Schubert, A.: Micro Structuring of Carbide Metals Applying Jet Electrochemical Machining, In: Precision Engineering, Volume 37, Issue 3, Juli 2013, Pages 621-634