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Surface Characterization of Particle Reinforced Aluminum-Matrix Composites Finished by Pulsed Electrochemical Machining

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Abstract

Aluminum matrix composites (AMCs) are difficult to machine conventionally. Pulsed Electrochemical Machining (PECM) is an alternative method to machine AMCs. Metals can be machined without contact, independent of material hardness and without mechanical or thermal impact. During the process no tool wear occurs. The AMCs consist of an aluminum matrix, which is easily to machine with PECM, and SiC-particles, which cannot be dissolved during the electrochemical machining process applying neutral electrolytes. This combination leads to a special behavior of dissolution and anodization. In this study, the influence on the surface layer, caused by Pulsed Electrochemical Machining of AMCs, is analyzed.

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Keywords: Pulsed Electrochemical Machining , Micro machining, Particle Reinforced Aluminum, ECM

1. Introduction

In the Collaborative Research Centre SFB 692 HALS at the Technische Universität Chemnitz several academic institutions work on high-strength Al-based lightweight materials for safety components. Such materials are investigated from the development process, different production methods and machining up to potential applications.

One of the material groups investigated, are aluminum matrix composites (AMCs). The AMCs, which are developed within the SFB 692, consist of the alloy EN AW 2017 as aluminum matrix, reinforced by 10% SiC-particles. The particles have a diameter of less than 1 µm. Due to the production of the composite by high-energy ball milling and hot isostatic pressing, the AMCs have an ultra-fine grained structure [1]. Figure 1 shows a metallographic micrograph of the investigated AMC EN AW 2017.

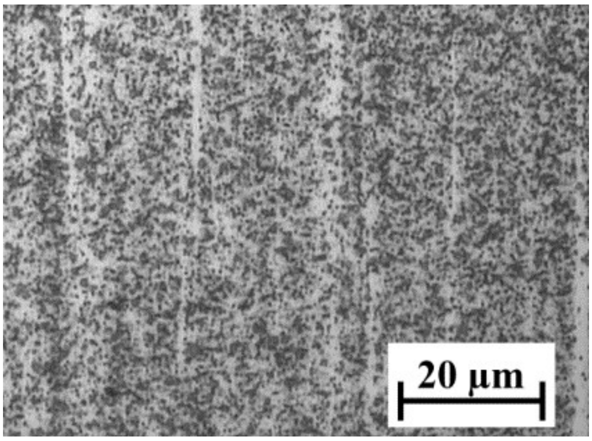

Fig. 1. Metallographic micrograph of an AMC consisting of EN AW 2017 reinforced by 10% SiC-particles

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The light regions represent the aluminum matrix while the dark regions represent the SiC-particles. During the preparation of the metallographic specimen the aluminum matrix is removed by etching. The etchant does not react with the covalent-bonded SiC-particles. Therefore the particles were exposed or flushed away if not embedded deep enough in the aluminum matrix. For that reason it seems that the specimen contains more than 10% of reinforcement particles in the micrograph.

Because of the hard ceramic particles, these materials are difficult to machine mechanically. Mechanical machining of AMCs is characterized by high tool wear. Furthermore the resulting heat influences the surface layer and the ultra-fine grained structure. Since the microstructure should not be affected, electrochemical machining represents an alternative for finish-machining of AMCs. Therefore, the material specific parameters in Pulsed Electrochemical Machining of EN AW 2017 reinforced by 10% SiC-particles are analyzed in this study.

2. Pulsed Electrochemical Machining (PECM)

Electrochemical Machining (ECM) is based on the local anodic dissolution of metallic work pieces. The cathode is the tool, while the anode is the work piece. The process-related working gap between the electrodes is flushed with an electrolytic liquid to guarantee the electrical current flow. The work piece is dissolved by emitting metal ions into the electrolyte due to electric charge exchange [2–4].

ECM has several advantages. The main advantage of ECM is the high removal rate and the independence of the material's strength and hardness. Another advantage is the slight influence on the microstructure. [2–4].

A further development of ECM is pulsed electrochemical machining (PECM). This technology is characterized by the application of pulsed direct current. Between the current pulses the electrolyte flushing is done, which offers a good supply of fresh electrolyte and therefore almost constant processing conditions. In this study, an additional mechanical oscillation of the tool cathode is applied as illustrated in figure 2.

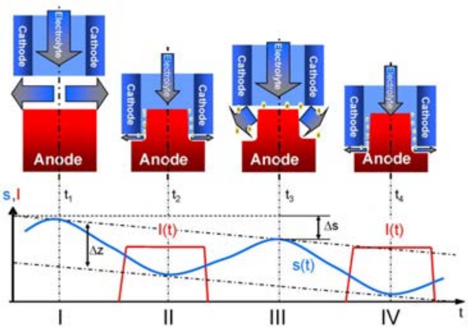

Fig. 2. Principle and phases of pulsed electrochemical machining with oscillating tool cathode [2]

In step I, the tool cathode and the work piece are aligned with each other with a large gap and a high amount of electrolyte is flowing through the working gap. The cathode is fed towards the anodic work piece and the tool oscillation is at the highest position. In step II, the cathode oscillation has reached its deepest position. A voltage pulse is initiated at this point where the working gap is minimal and the anode is ablated. Only a small amount of electrolyte is flowing through the small gap. Afterwards, in step III, the cathode is moved back and the working gap is increased. This leads to an increase in electrolyte flushing rate, which guarantees the removal of reaction products, wasted electrolyte and heat as well as the supply of fresh electrolyte. [2]

PECM with an oscillating tool allows to further increase the achievable surface quality and the accuracy of the process. The experimental analysis of the material specific parameters was performed with a PEMCenter 8000 from PEMTec SNC, France. The experimental parameters are shown in table 1.

Table 1. Experimental PECM parameters

Parameter	Values
Work piece material	EN AW 2017 + 10% SiC-particles
Cathode material	Stainless steel 1.4301
Diameter of specimen and cathode	12 mm
Electrolyte	$NaNO_3$
Electrolyte conductivity [mS/cm]	68
Electrolyte temperature [°C]	20
Electrolyte pressure [kPa]	300
Voltage pulse amplitude [V]	5.9, 6.5, 7.4, 8.3, 9.2, 10.1, 11.9, 12.8, 13.7
Voltage pulse frequency [Hz]	50
Voltage pulse duration [ms]	4
Cathode feed rate [mm/min]	0.01, 0.04, 0.09, 0.14, 0.19, 0.24, 0.29, 0.34, 0.39, 0.44

The experimental setup is shown in figure 3.

The yellow cathode and the light-grey AMC specimen have cylindrical shapes with a diameter of 12 mm and plane surfaces. The cathode is fed vertically down towards the AMC specimen, which were prepared by mechanical milling. The electrolyte, which is highlighted in blue, is supported in horizontal direction through the working gap. A process chamber guarantees an electrolyte flow with predefined direction and constant pressure [5].

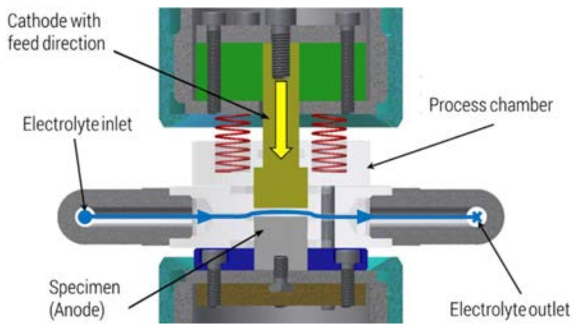

Fig. 3. Section view of the experimental setup [5]