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Generation of Defined Surface Waviness on Tungsten Carbide by Jet Electrochemical Machining with Pulsed Current

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Abstract

Conventional machining of WC6Co carbide metal is challenging due to its mechanical properties. Electrochemical machining applying a continuous free jet and pulsed current (Jet-PECM) is a promising alternative for surface structuring of this material, because the resulting removal only depends on its electrochemical properties. Neither tool wear nor thermal or mechanical influence on the work piece is caused by this process. In this study the influence of current pulse parameters on the cross-sectional shape of straight-lined grooves machined with Jet-PECM in WC6Co was analyzed. Furthermore adequate machining strategies were derived and applied in order to generate surfaces with defined waviness.

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Keywords: Electrochemical Machining (ECM), Pulsed Electrochemical Machining (PECM), Electrolyte Jet, Tungsten Carbide

1. Introduction

The basic principle of electrochemical machining is 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, which is a liquid ion conductor. The special characteristic of Jet-ECM is the supply of fresh electrolyte through a micro nozzle with a mean jet velocity of approximately 20 m/s [1,2,3,4].

The electrolyte is ejected perpendicularly towards the work piece surface in the form of a closed free jet surrounded by atmospheric air. This leads to a highly localized machining area, because the distribution of the current density is locally confined by the impinging jet.

Extremely high current densities up to 2000 A/cm² in the jet can be realized [1,2,5]. Thus excellent surface qualities can be machined in steel materials. In addition, the high jet velocity leads to a very good supply with fresh electrolyte. Hence, there is no need for interrupting the process for flushing phases when steel materials are machined.

Since WC6Co-type hard metal is a composite material consisting of covalent-bonded hard particles embedded in a metallic binder material, the electrochemical dissolution of this material differs significantly from comparatively easy to handle materials like pure iron or steel alloys [6,7]. Hence, several investigations were carried out to investigate Jet-EC machining of grooves by one-axis and multi-axes nozzle movements [2,7,8,9]. In summary it was found out that electrochemical machining of WC6Co is possible when applying an electrolytic liquid composed of 1.2 mol/l NaOH and 2.4 mol/l $NaNO_3$. [7]

In this study pulsating electric currents (Jet-PECM) are used through applying rectangular voltage pulses with frequencies in the range of 5 Hz to 80 Hz. It is expected that the formation of passivating oxide layers is reduced by the current pulsation, which leads to increased removal depths.

The duty cycle, which is the relation between the pulse-on-time and the total pulse duration, was increased from 50% to 90%. It is expected that an increasing duty cycle leads to an

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increase of the ablated volume as the duration of the machining pulse is increased.

2. Experimental Setup

For the experimental investigations in Jet-PECM, a modular test rig was used [1,2]. A 3-axis positioning system was applied to realize the relative movements between the nozzle and the work piece. The machine frame in gantry design and the working table are made of granite, which guarantees the required mechanical and thermal stiffness for micro-machining applications.

The electrolyte was supported by a pulsation-free pump to the nozzle and ejected vertically downwards to the work piece. Used up electrolyte was collected in a disposal tank. The circuit diagram in figure 1 illustrates the electrical setup.

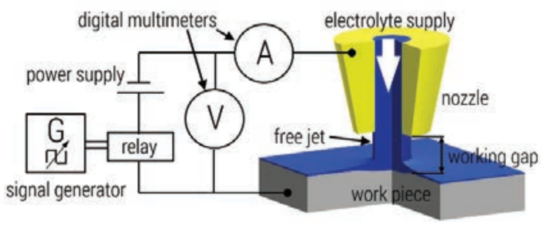

Figure 1. Circuit diagram of the Jet-ECM test rig

A Keysight N5771A power supply was used to provide the process energy. The rectangular signal for the current pulsation was provided by a Keysight 81150A signal generator and a Crydom D4D07 semiconductor relay, which is triggered by the function generator. Two Keysight 34465A multimeters were used to detect the voltage and current signal.

All electrical and kinematic operations are controlled by a personal computer. Therefore, customized control software based on National Instruments LabVIEW was developed.

3. Design of Experiments

According to earlier experiments in Jet-ECM on WC6Co the processing parameters charted in table 1 were applied to generate defined surface waviness [7].

Table 1. Jet-PECM parameters

Parameter	Symbol	Value
Electrolyte, type and concentration		$NaNO_3$, 2.4 mol/l
		NaOH, 1.2 mol/l
Work piece material		WC6Co (CTE12A)
Nozzle inner diameter	D	100 µm
Pump delivery rate	dV/dt	10 ml/min
Initial working distance	g	100 µm
Nozzle motion speed	v	200 µm/s
Amplitude of voltage pulsation	U	60 V
Frequency of voltage pulsation	f	10 Hz
Duty cycles of voltage pulsation	dc	60%, 80%, 90%
Line spacing of linear removals	S_L	400 µm, 350 µm, 300 µm

The work piece material CTE12A was obtained from Ceratizit Group, Luxembourg. CTE12A is a WC6Co type hard metal with an average WC grain size of approximately 2.5 µm to 6.0 µm. The work pieces were pretreated by mechanical face-grinding, hence an initial surface finish of Ra = 0.1 µm and Rz = 0.5 µm was obtained.

In Jet-PECM a pulsating current is applied, which results from a pulsating voltage signal. The graph in figure 2 shows an exemplary voltage signal generated by the signal generator.

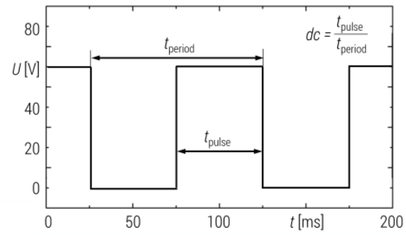

Figure 2. Rectangular voltage signal with amplitude 60 V and frequency 10 Hz, idealized signal

Rectangular voltage pulsations with an amplitude of 60 V and a frequency of 10 Hz were applied. The duty cycle represents the ratio between the duration of the voltage pulse and the total period time.

Rectilinear grooves were arranged parallel to each other to generate defined surface waviness as shown in figure 3

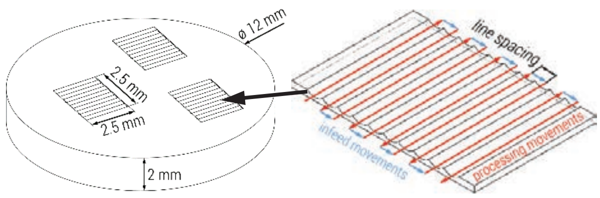

Figure 3. Overview of a sample (left) and detailed view on wavy surface with Jet-PECM nozzle movements (right).

Rectangular machining areas with an edge length of 2.5 mm were arranged on the WC6Co sample billets, which offered a diameter of 12 mm and a height of 2 mm as sketched on the left-hand image. On the right-hand image a detailed sketch of the nozzle movements is depicted. While the processing movements are highlighted as red lines, the infeed movements are marked in blue. The line spacing represents the lateral distance between the parallel processing movements.

The line spacing was kept constant for each sample and varied from one sample to another in order to generate different amplitudes and wavelengths. The design of the expected cross-sectional waviness profiles are shown in Figure 4.

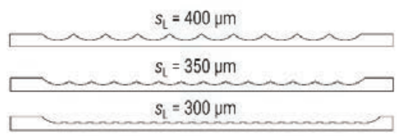

Figure 4. Expected results of the cross-sectional profiles of surface waviness at decreasing line spacing