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Structuring of wear-affected copper electrodes for electrical discharge machining using Pulse Electrochemical Machining

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ABSTRACT

The wear in electrical discharge machining exerts a great influence on the result and quality of the workpiece being machined. Especially complex structures can lead to high costs for electrode preparation. In this investigation a process chain is set up using copper electrodes machined by Pulse Electrochemical Machining for structuring hard metal by die-sinking electrical discharge machining. After investigating the electrochemical machining behavior of copper, suitable parameters are defined for this wear-free working process. In the succeeding electrical discharge machining three consecutive structuring steps are performed using a new tool electrode each time. Reproducing four complex structures and estimating a validation factor for the reproducibility, it is shown that the introduced sequence can be used for machining complex shapes on hard metal.

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1. Introduction

New technologies and new materials will demand new tooling solutions [1]. Hence the conventional area of application for hard metals extends and new requirements towards surface structure and geometry have to be met. Rajurkar et al. pointed out that increasingly harder materials for precision tools lead to difficulties in machining [2]. Electrical discharge machining (EDM) is a commonly used process for machining hard-to-machine materials like hard metals. Being independent from the material's hardness and offering the possibility of producing many different geometries, this process seems predestined for such machining tasks. The occurring sparks between tool electrode and workpiece are able to melt a certain volume of material at the surface of each pole [3], which is then flushed away by a dielectric. This volume depends on the amount and the distribution of the transferred energy to the electrodes and the dielectric [4,5]. However, the electrodes in use, mostly made of electrolytic copper or tungsten copper, suffer a significant amount of wear in machining, which is most distinct on edges [6]. Thus it is necessary to use a new electrode for each individual workpiece to ensure a good finish.

In contrast, Pulse Electrochemical Machining (PECM) is a process which uses anodic metal dissolution in an electrolyte, thus the tool does not suffer significant wear [7]. Unlike in conventional ECM, the feed in PECM is superimposed with a vibration of the tool in order to achieve small gap widths to improve the accuracy [8]. The application of the electrical pulse is triggered when the cathode is at the bottom dead center of the vibration and thus leads to a precise chemical dissolution of the workpiece at a small gap width only. As is the case in EDM, the inverted shape of the tool, scaled in size by the gap width, is reproduced in the workpiece, whereat the gap width in PECM depends on the conductivity of the electrolyte as well as on the applied voltage and the pulse on-time [9]. PECM allows for the machining of complex structures and the creation of a good surface without tool electrode wear. Disadvantageously, materials that build a strong passive layer or have different components can cause difficulties in PECM machining. For example hard metals represent a major challenge for PECM since they contain different components showing different electrochemical behavior [10,11]. Additionally, when machining tungsten carbide a passive layer of tungsten trioxide develops, which prevents further dissolution. Though it could be shown that pure tungsten carbide can be machined under "near ECM conditions" in an alkaline electrolyte mixture of ammonia and sodium nitrate, the problem then arises that in this pH range the cobalt binder phase forms passive layers [12]. At the moment hard metal cannot be machined satisfactorily by PECM.

Since both PECM and EDM use a negative–positive reproduction of the tool electrode, it is necessary to prepare the tool or "master electrode" with the desired negative structure in a previous step. As PECM has the advantage of working nearly wear-free, the effort of structuring the master electrode has to be taken only once. Taking these facts into account, a process chain can be built up which first structures electrodes by PECM and then uses them in EDM (see Fig. 1 for the process chain principle). The easy structuring and restructuring of worn electrodes

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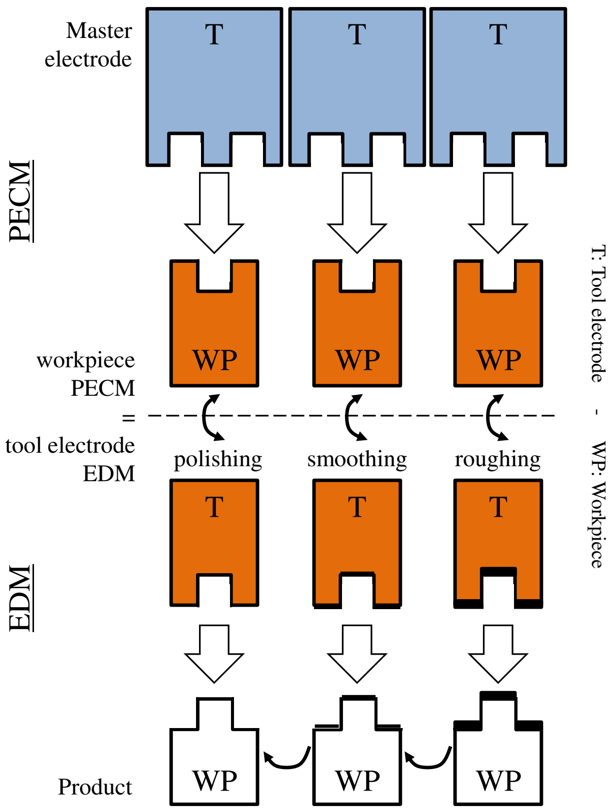

Fig. 1. PECM–EDM process chain principle.

by PECM allows using a "new" tool electrode for each EDM step. Due to the small discharge energies used for machining hard metal, the heat-affected zone induced by EDM has no influence on the machinability of copper in a following PECM process, which allows for the restructuring of worn electrodes [13]. This way, the need for electrodes in EDM can be met by a series production of electrodes by PECM. Since the negative–positive reproduction is used twice in the process chain, the master electrode must have the desired final structure, taking into consideration the gap width of both processes.

The present study deals with the machining and reproduction of four different structures in hard metal using electrodes made of electrolytic copper (ECu). This contribution is based on an extended abstract and presentation given at the ICSHM10 [14]; however, even though the same structures were used, completely new experiments and measurements were conducted.

2. Experimental setup

The experiments were conducted on industrial-size machines, namely a *PEMCenter 8000* by *PEMTec SNC* France using aqueous sodium nitrate as electrolyte for the electrochemical machining and a *FORM20* by *+GF+ AgieCharmilles* using *Oelheld IonoPlus IME-MH* dielectric for the electrical discharge machining.

In order to get an understanding of the copper behavior under PECM conditions, experiments were conducted to investigate the correlation between feed rate [mm/min], gap width [mm], specific material removal (SMR) [mg/C] and the current density [A/mm^2] using concentrically positioned cylindrical electrodes with a diameter of 10 mm. The tool, made of high grade steel 1.4571 (AISI 316Ti), was turned to a roughness of $R_z \approx 1.42$ µm. To provide reproducible flushing conditions a flushing chamber was used, see Fig. 2. This setting having no side gap, the measured current only dissolved the material in the frontal gap. As the pressure was set to 200 kPa the flow rate depended on the individual gap

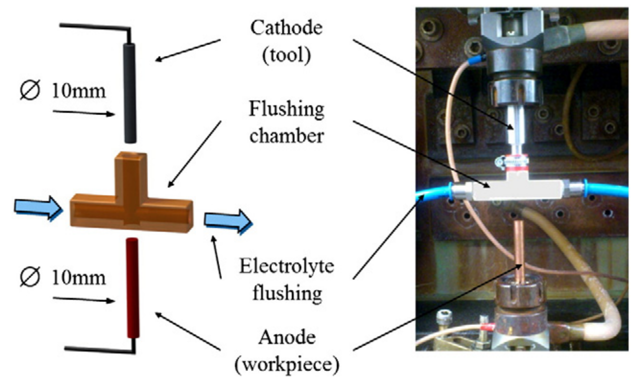

Fig. 2. Experimental setup for removal efficiency investigation.

width and was in the range of 7.2–9.5 l/min; the further boundary conditions were as follows:

• $NaNO_3$ concentration	75 g/l (technical pure)
• Electrolyte conductivity	$\sigma = 71 \pm 1$ mS/cm
• Electrolyte temperature	$T = 20 \pm 1$ °C
• pH value	7.1 ± 0.2
• Pulse on-time	2 ms (at 50 Hz)
• Voltage	7 V; 10 V

The results are used to identify the material behavior of electrolytic copper and define a suitable working point. The geometries to be machined by the PECM–EDM process chain are selected to cover rough and fine surface structures as well as sharp edges and round shapes, namely "file rough", "file fine", "golf ball" and "saw tooth", cf. Fig. 3 showing photos of the master electrodes from top view, drawings from the side and the measured attributes, which can also be found in the results (Table 3).

The master electrodes consist of different materials: tool steel for file rough and file fine, pure nickel for golf ball and high grade steel for saw tooth, resulting in different process behaviors in PECM, so each parameter set was developed individually. In these experiments free electrolyte flushing was used with the pressure also set to 200 kPa. Table 1 shows the parameters of the machining program used in the PECM process, which consists of two phases, a structuring phase up to a constant current density (step 1), meaning that the desired structure is basically developed, and a smoothing phase with a lower voltage and a shorter pulse on-time but a higher current density for obtaining a more precise structure and smooth surface (step 2).

The value "phase" is used for shifting the start time of the pulse with regard to the bottom dead center of the mechanical vibration, following formula (1). Due to gas evolution in the PECM process inhomogenities of the electrolyte conductivity can result during the pulse on-time leading to problems. Shifting the start can improve the stability as gas bubbles are compressed. A phase of 75% or 85% showed the best results concerning pulse stability.

$$t_{start}\,[\mathrm{ms}] = -t_{on}[\mathrm{ms}] \times \frac{\mathrm{phase}\,[\%]}{100}. \quad (1)$$

Fig. 4 exemplarily shows the current in red and the voltage in blue when machining the golf ball structure. As can be seen, the drop in

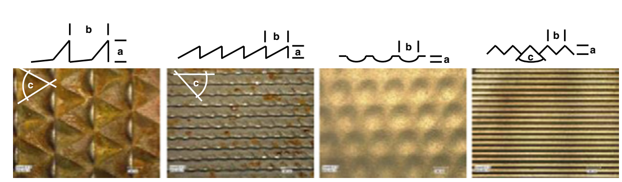

Fig. 3. Master electrodes for PECM and measured attributes.

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