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Influence of an inner flushing concept on the recording of material characteristics in electrochemical machining of Nickel 201

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Abstract

Machining processes such as precision machining technologies for components are looking for further development and optimization in manufacturing technology. This also includes Electrochemical Machining (short: ECM), for which there is a high need for research, because the dissolution behavior for each material is different and the development for a tool is very complex, although this process has long been established in technical applications. Electrochemical machining is based on anodic metal dissolution, for which an active medium must be supplied to and removed from the machining site.

Usually, rapidly dissolving materials such as nickel 201 are very susceptible to flushing grooves, which greatly reduce the quality of the workpiece in terms of its functional surface. For this reason, optimized flushing scenarios are investigated with the help of fluid flow simulations and implemented in a new designed flushing chamber.

The aim of this paper is to record the material characteristics when using a new developed flushing chamber and tool with a reversed inner flushing system. This is intended to validate an improvement in the surface of highly dissolvable materials and demonstrate the reduction of flushing grooves.

1 Introduction

In today's technological progress, pure nickel alloys are becoming more important to produce precision resistors and other electrical components such as semiconductors [1] in the chip industry. For this purpose, surfaces with low roughness are of high significance [2].

The manufacturing of functional surfaces with a defined surface roughness is becoming increasingly important in production technology. Electrochemical machining is suitable for the manufacturing of components with high demands on dimensional tolerances and defined surface properties. The ECM process is a non-contact fine machining process with low thermal impact on the workpiece. It is based on the principle of anodic metal dissolution, whereby flushing with aqueous electrolyte between the workpiece and the tool is essential and can influence the machining result. [2,3]

Electrochemical machining can be improved by using internally flushed tools and can therefore be adjusted for machining with small gaps. In the electrochemical processing of reactive materials such as nickel, passivation occurs at low current densities, which inhibits surface processing. When using internally flushed tools, however, the high pressure of the electrolyte and the reactive dissolution behavior of nickel lead to the strong formation of flushing grooves, which in turn have a strong negative effect on the surface quality. [4]

The aim of this work is to improve the machining results by developing a flushing chamber to guide the internal flushing during electrochemical nickel machining. The main goal is to design a flushing chamber that optimizes the flushing conditions in the machining gap and thus minimizes the formation of flushing grooves and positively influences the material removal properties. The flushing properties are first to be investigated by simulation and optimized for the machining process. Finally, the simulated results are to be validated in the real process and material characteristics are to be developed under the new flushing conditions.

2 Experimental setup

Preliminary work has shown that machining nickel using a tool with internal flushing shows good working results, but the formation of flushing grooves is favored, which negatively affects the surface quality [4]. Such a setup has

already been used in [4] for investigations of the dissolution behavior of Nickel 201 and is shown in the following figure.

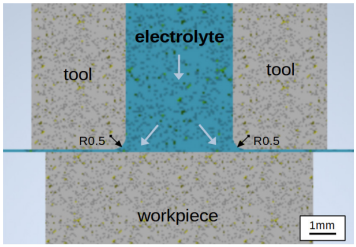

Figure 1: *Half section through the experimental setup for internal flushing [4].*

This experimental setup is the starting point for the development of a flushing chamber that improves the flushing conditions with the goal to minimize the formation of flushing grooves.

2.1 Simulation of a flushing chamber

The design idea of the flushing chamber bases on the generation of counter-pressure in the working gap to minimize the fluctuation of the electrolyte, which has been identified as one cause of the formation of flushing grooves. Furthermore, the flushing chamber should be designed in such a way that two modes can be realized. On the one hand flushing through the tool with the flushing chamber acting as outlet, and on the other hand flushing through the chamber with a drilling in the tool forming the outlet. The two flushing modes are shown schematically in the following figure.

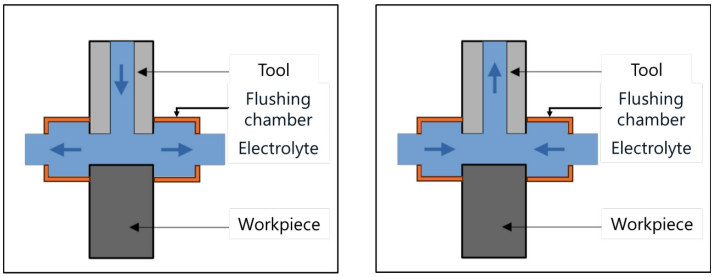

Figure 2: *Used flushing modes: Inner flushing mode (left) and external flushing mode (right).*

A cylindrical hollow volume that decreases exponentially towards the working gap is assumed as the initial volume for developing the flushing chamber. Flow simulations with Autodesk CFD 2024 were used to determine the number and arrangement of the flushing outlets and inlets. Here, a flushing chamber with

three- and four-flushing outlets were attached to the hollow cylinder and then the “Water Age” within the flushing chamber were simulated and evaluated. The “Water Age” describes the amount of time the electrolyte spends throughout the chamber. This quantity shows in which regions the electrolyte is stagnant and where it’s free flowing. The simulations carried out are shown in the following figures.

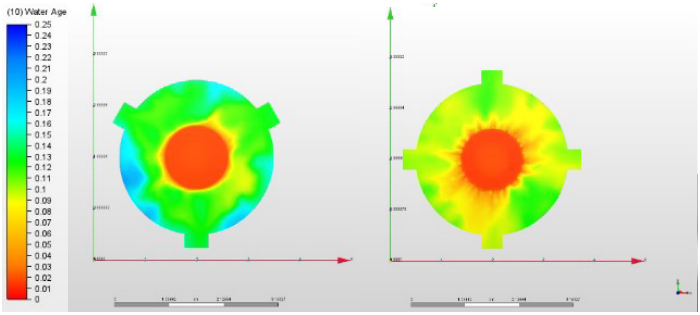

Figure 3: *Flow simulation with inner flushing mode: 3-outlets (left) and 4-outlets (right).*

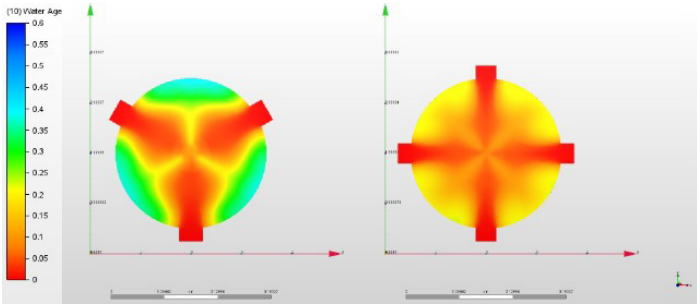

Figure 4: *Flow simulation with external flushing mode: 3-inlets (left) and 4-inlets (right).*

The simulation value of the “Water Age” is decisive here, as it indicates how long the electrolyte remains in a respective position of the flushing chamber. Therefore, short times indicate a fast electrolyte exchange. The simulations thus clearly show that the electrolyte remains in the working gap and in the flushing chamber for significantly shorter times for flushing chamber with 4 outlets than for a flushing chamber with 3 outlets. For this reason, a flushing chamber with 4 outlets is constructed for further investigations of the dissolution behavior of nickel, because this chamber shows the best flushing properties.

2.2 Validation of the flushing chamber setup

The investigations were carried out on the PemCenter 8000 from PemTec SNC. Round bars with a diameter of 10 mm made of nickel 201 are used as sample material. The electrolyte used in the experiments is an aqueous $NaNO_3$ solution with a conductivity of 85 mS/cm. In the experimental setups two flushing modifications were used, as shown in figure 2. For both setups a tool made of a stainless-steel round bar with a diameter of 11 mm with a drilling of 4 mm in the middle is used, the end face is positioned centrically to the workpiece. The used experimental setup is shown in the following.

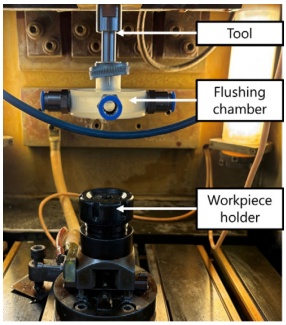

Figure 5: *Experimental setup.*

The used machine-related input parameters were taken from [4] to show the improvement of the results by using a flushing chamber with an inner-flushed tool and are shown in table 1. The feed rates v_f ranged from 0.1 mm/min to 0.55 mm/min in 0.05 mm/min steps. Machining was stopped as soon as an equilibrium gap was reached.

Table 1: *Machine parameters of the ECM machining process for internal flushing.*

Voltage U	***Pressure p***	***Pulse width t_{Puls}***	***Frequency f***	***Phase P***	***Feed rate v_f***
18.7 V	*4 bar*	*5 ms*	*50 Hz*	*50 %*	*0.1 – 0.55 mm/min*

For the setup with the external flushing the used machine-related input parameters were determined by preliminary tests and are shown in table 2. The feed rates v_f ranged from 0.1 mm/min to 0.5 mm/min in 0.1 mm/min steps and from 0.5 mm/min to 0.75 mm/min in 0.05 mm/min steps to have a higher accuracy in higher current density range. In addition, to keep the measurement error below 1%, a minimal material removal of 0,5 mm height was performed for all specimens during the tests, because the used precision scale K-M SRK-100 by Krahl-Messtechnik (Bovenden, Germany) has a precision of d = 0.001 g.

Table 2: *Machine parameters of the ECM machining process for external flushing.*

Voltage U	Pressure p	Pulse width t_{Puls}	Frequency f	Phase P	Feed rate v_f
18.7 V	4 bar	5 ms	50 Hz	50 %	0.1 – 0.75 mm/min

A total of 3 series of experiments were carried out for each of the two flushing methods, each with 10 feed rates, so that material characteristics could be recorded over a wide current density range.

3 Results and discussion

The feed rate v_f, the specific mass removal rate SMR and the arithmetical roughness Ra are used as result variables for both flushing modes. The several results are plotted as a function of the current density. Figure 6 shows the feed rate v_f against the current density J for both flushing modes.

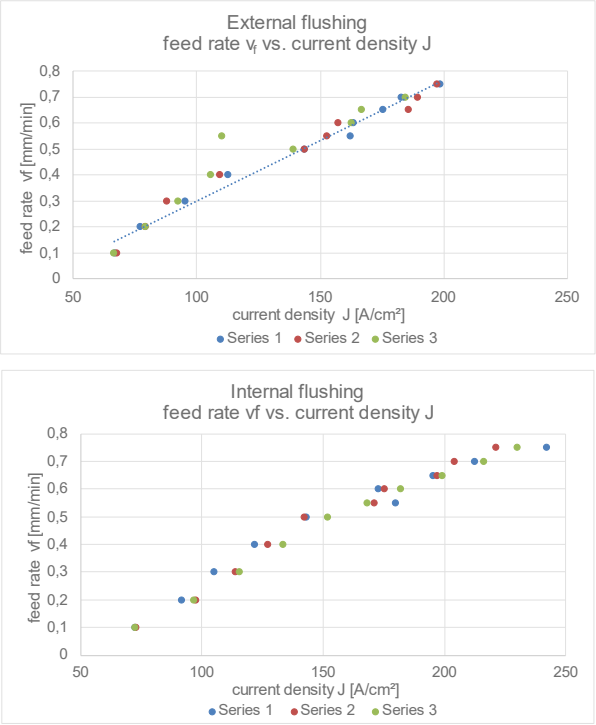

Figure 6: *v_f-J characteristic curve for external (up) and internal flushing (down).*

For both modes of flushing, a linear relationship between the variables can be seen. With external flushing, the current density increases linearly up in the high feed range. This behavior can be explained by the physical relationship of Ohm's law. The increase in feed speed reduces the resulting gap width within the machining process and the resulting reduction in electrical resistance causes the current density to increase linearly to the change in feed rate. By using a flushing chamber, the flushing can be improved during machining, whereby high current densities can be achieved, which can suppress the formation of oxide layers, which are characteristic of nickel 201, and thus improve the surface quality. Current densities of up to 197.7 A/cm^2 can be achieved with external flushing, and up to 220.8 A/cm^2 with internal flushing. The measured gap widths up to 20 µm during machining with external flushing is smaller than by internal flushing with 40 µm, which indicates more accurate machining with better surface quality. This is also shown by looking at the arithmetical roughness value Ra representative of the surface characteristics in Figure 7.

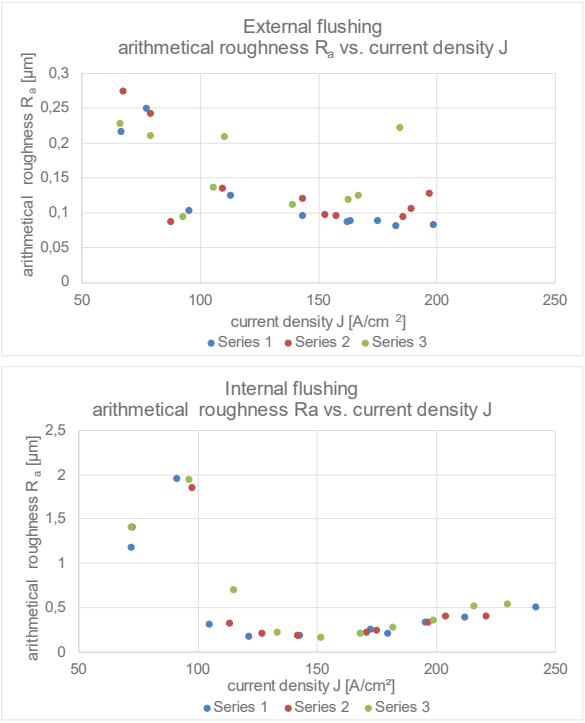

Figure 7: *Arithm. rough. Ra over current density J for external (up) and inner flushing (down).*

The roughness of the surface was measured by tactile evaluation on a perthometer MarSurf XR/XT20 by Mahr (Göttingen, Germany). The arithmetical roughness Ra was averaged over 2 measurements from the sample surface. In the feed rate range considered, lower roughness can be achieved with external flushing. This can also be explained by the smaller gap widths of the external flushing mode. With internal flushing, a greater scattering of the values can be seen. One reason for this is instable flushing by high gap widths, so there are turbulences in the electrolyte, which results in an unstable machining process. By small gap widths there is the formation of flushing grooves, which reduce the surface quality. Another important parameter to develop an efficient machining process is the specific material removal. The SMR over the current density of the experiments is plotted in figure 8.

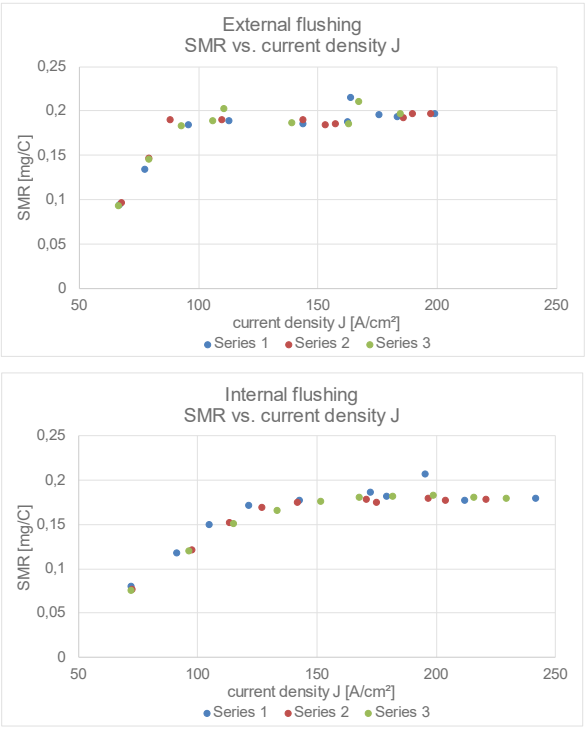

Figure 8: *SMR-J characteristic curve for external (up) and internal flushing (down).*

For both types of flushing, an increase in the SMR value with increasing current density can be seen. With an increase in current density, more electrical energy is introduced into the system, which is used to dissolve the material, thus is

explaining the proportional relationship between the current density and the SMR. This value settles around 0.2 mg/C. In addition, with external flushing, the SMR is formatting a little higher than with internal flushing. Although a higher current density is achieved with internal flushing, there is no higher SMR than with external, which indicates that during internal flushing, the electrical energy is diverted to chemical side reactions such as the formation of oxide layers in addition to the dissolution reaction.

4 Conclusion and outlook

With a flushing chamber by machining with an inner-flushed tool, smaller gap widths and thus lower roughness can be achieved with less flushing grooves. But also, in this case the problem of the flushing grooves is not completely solved and so the electrochemical machining process is not optimal yet. There are still bad flushing conditions in the working gap by the inner flushing mode, so the electrolyte is dispersed towards the flushing outlet. In this case there are bad electrolyte conditions because of ablation particles und fluctuations so the formation of the electric field and thus the current density is not optimal. Low current densities then lead to the formation of oxide layers and poor processing, resulting in bad surface qualities on the sample material. When observing the external rinsing, a stable rinsing process is observed which therefore also results in a stable formation of an electric field. Although the current densities achieved are lower than with internal flushing, better surface qualities can be reached due to the lamellar flushing direction. The artifacts that can be observed on the sample surface during external flushing can be traced back to internal structures of the flushing chamber, which have a negative local influence on the flushing. In further investigations, the internal structure of the flushing chamber can be further optimized to further improve the flushing process and ensure turbulence-free flushing. This means that nickel can be processed without artifacts on the surface. Furthermore, the inner flushing mode can be investigated in more detail, whereby the limiting factors are, that despite high current densities, there is an affinity for passive layer formation of the sample material nickel and how this can be suppressed by adapting the flushing chamber or the machine process.

Acknowledgements

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