euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Helical electrodes for improved flushing conditions in drilling EDM of MAR-M247

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Abstract
The machining of precision holes in difficult to machine materials or alloys with high aspect ratios ϕ and under consideration of the cost-effectiveness of the overall process is still a challenge. Electro-discharge machining (EDM) is predestined for such purposes. Flushing is one key factor for the precise machining of bore holes with high aspect ratios ϕ. Nevertheless, the capabilities of the flushing conditions are often underrated regarding an improved process stability, an increased material removal rate V_W, a decreased machining time t_{ero}, as well as the tool wear Δl_E. Therefore, the present investigation considers the influence of an outer geometry of cylindrical rod tool electrodes to improve the electro-discharge drilling process. Different electrodes made of brass, with helical flutes along the shank, are compared with the basic geometry, a cylindrical rod electrode, with respect to their flushing capabilities. All electrodes have an outside diameter d = 3 mm. It is suggested that the machining process will stabilise and the material removal rate V_W will increase due to improved removal efficiency of erosion particles (debris). Through holes with a total depth h = 16 mm have been machined by use of Design of Experiments (DoE) approved process parameters in nickel based superalloy MAR-M247. By use of a helical shaped electrode the machining time t_{ero} was reduced by 39 % compared to the cylindrical rod electrode.

Keywords: electro-discharge machining, flushing, helical electrodes

1. Introduction

Electro-discharge machining (EDM) is a process with widespread practice in the industry. It is used to machine hard and brittle metals to produce complex geometries and small features with high precision. The flushing conditions, although seldom considered, have the potential to increase the material removal rate V_w, to stabilise the process, improve the processing accuracy A_p, and decrease the overall machining time t_{ero}.

Especially high aspect ratio holes in difficult to machine materials or alloys are challenging, in particular because of the difficulty to achieve sufficient flushing conditions in the frontal gap s_L of the bore hole. The use of external or internal flushing, i.e. by high pressure flow through a tube electrode, is one way to improve flushing conditions though needing extra effort and equipment, like a high pressure pump. The machining of cooling holes inside turbine blades specifically requires a fast and precise machining process. This is why the presented study on drilling holes with high aspect ratios ϕ is performed in nickel based superalloy MAR-M247. Newly developed helical electrodes are used as an alternative to active flushing.

Up to now, there is no systematic investigation of helical structures as outside geometric features of tool electrodes. Plaza et al. [1] studied the influence on machining time t_{ero}, tool wear Δl_E and material removal rate V_W for drilling in Ti-6Al-4V [1]. The influence on inlet diameter d_i and outlet diameter d_o of bore holes was examined by Hung et al. [2], other researcher used helical electrodes for improving wire ECM [3, 4]. Other approaches for outside geometries included slotted rod electrodes [5] or a counteractive double helix [6].

The use of a helical groove as an outside flow channel is expected to increase the mass flow rate $\dot{m}$ of liquid to the bottom of the bore hole as well as ejecting debris and gas bubbles from the working gap s.

2. Experimental setup

Different helical grooves along brass rod electrodes with a diameter of d = 3 mm were machined using the automatic CNC lathe Cincom B12E by Citizen Machinery Europe GmbH, Esslingen, Germany. The machine tool enables the use of milling tools, perpendicular to the workpiece, here the brass electrodes. Adapting the feed f and rotation speed n of the automatic CNC lathe, helical grooves with depth of d_{f1} = 0.1 mm, d_{f2} = 0.3 mm, d_{f3} = 0.5 mm, and d_{f4} = 1.0 mm and flute angles of α_1 = 15°, α_2 = 30°, α_3 = 45°, and α_4 = 60°, resulting in different pitch lengths P, were produced to cover a great variety of grooves. The overall length of the electrodes was l = 60 mm, where the helix length is l_h = 50 mm, see figure 1 for visualisation.

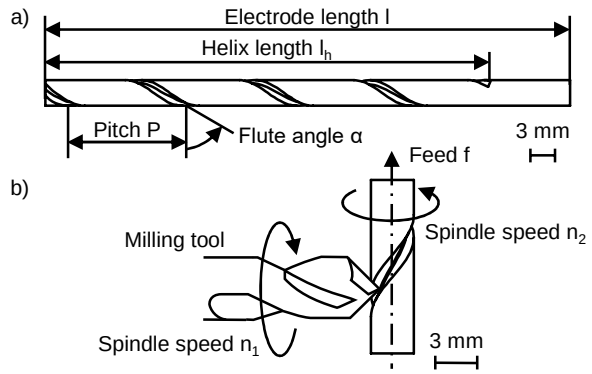

Figure 1. a) Geometry of helical electrodes and b) production schematic

For all drilling EDM experiments the die-sinking EDM machine tool AGIE Compact 1 by AGIE, today Georg Fischer AG, Schaffhausen, Switzerland, was used. Process parameters were

optimised on the basis of the Design of Experiments (DoE) method with five factors leading to an experimental plan with 2^{5-2} combinations and two repetitions each. Every experiment was carried out in the same workpiece, at another position, and with a new tool electrode. The result of these experiments is the comprehension of the influence of each process parameter on the objective criteria machining time t_{ero}, linear tool wear Δl_E, and working gap s. In addition, each factor with a significant impact was further optimised in accordance to its influence.

3. Processing results

Figure 2 shows the optimised process parameters and the results of drilling through holes in MAR-M247 superalloy. The error bars indicate the standard deviation.

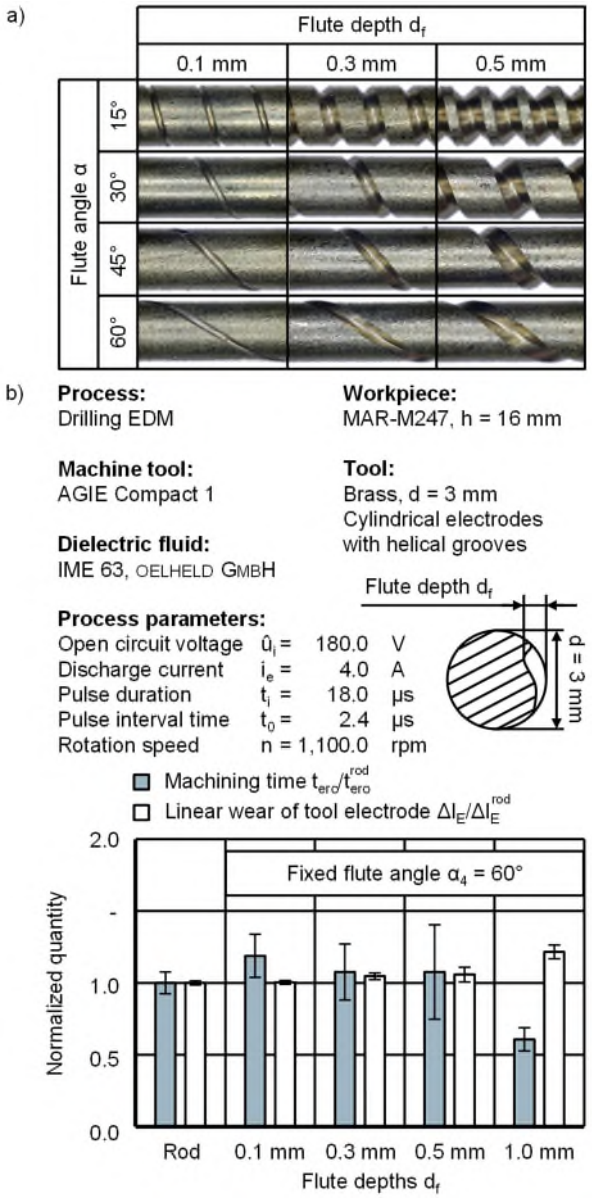

Figure 2. a) Side views of helical electrodes; b) Processing results of drilling EDM with helical electrodes, normalised with regard to a cylindrical rod electrode as reference

Comparing different flute depths d_f suggests that there is a minimum flute depth d_f needed to cause a positive effect on the debris and bubble transport out of the bore hole. The comparison of the cylindric electrode with no flute with the biggest flute depth d_{f4} = 1.0 mm shows the greatest improvement. The material removal rate V_W, being directly related to the machining time t_{ero}, increased by 39 %, although the linear tool wear Δl_E also increases, by nearly 25 %. The working gap s_{Lin} and s_{Lout} of the inlet and outlet bore hole reduced by 24.1 % down to s_{Lin} = 0,163 mm and 43.3 % down to s_{Lout} = 0,048 mm respectively. In general, the linear tool wear Δl_E slightly increases by use of helical electrodes. Notoriously, both the increase of material removal rate V_W and linear tool wear Δl_E is a consequence of the additional and effective flushing. This corresponds to the thesis, that the flushing conditions as well as the process stability are perceptibly improved and the machining time t_{ero} can be reduced by use of helical electrodes.

The variation of flute angles α let to the recognition that flute angles α_3 > 45° are needed to improve the machining time t_{ero}. This indicates that the debris, and especially the gas bubbles, also need a minimum flute angle α to be pulled out within the guidance and the extra space of the flute. The suction caused by the electrodes rotation towards the flute orientation visably enhanced the spin of debris and gas bubbles respectively.

Figure 3 moreover indicates the improvements by comparing the developments of the Z-axis positions during machining for five different electrodes. When reaching certain depths h, the Z-axis position z, being the sum of material removal of both tool and workpiece electrode, declines noticeably and the feed f decreases for all tool electrodes as a consequence of poor flushing conditions. The influence of flute depths d_f on the maching time t_{ero} to machine through holes, shown in figure 3, supports this statement. Flute depths d_f > 0.3 mm are needed to improve the process.

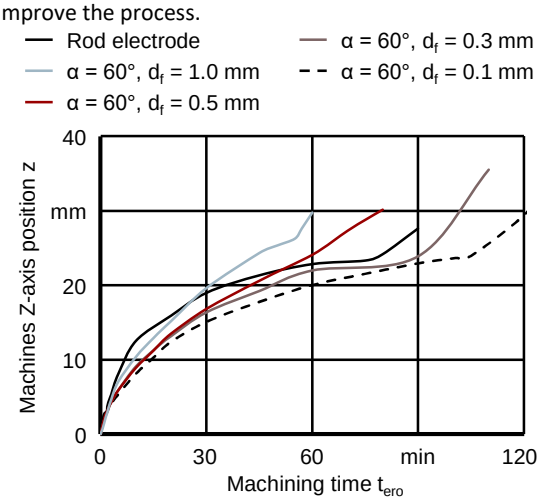

Figure 3. Development of Z-axis position with machining time t_{ero}; comparison of different electrodes

4. Summary and Outlook

Rod electrodes with external helical grooves and the influence of these helical structures were investigated. It was found that minimum flute depths d_f and flute angles α are needed to improve the drilling EDM process. The machining time t_{ero} could be reduced by 39 % by use of the deepest flute d_{f4} = 1.0 mm and biggest angle α_4 = 60°. In future experiments the setup will be extended to examine the effects of internal geometries too. Other areas of focus shall be the orientation and amount of helical grooves as well as the effect of internal flushing.

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