Micro channel fabrication on AA6063-SiC composites using micro ED milling

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Presented in International Conference on Precision, Micro, Meso and Nano Engineering (COPEN - 12: 2022)
December 8 - 10, 2022 IIT Kanpur, India

ABSTRACT

KEYWORDS

Micro ED Milling, Microchannel, Aluminium Composites, Multiple Passes.

Micro electric discharge machining (μED milling) has emerged as a suitable unconventional process for 3D machining in difficult-to-cut, electrically conductive materials. But the inherent tool wear in it affects the dimensional accuracy of the machined features limiting the widespread use of the process. In this work, microchannels were made on AA6063-4 wt. % SiC composites using μED milling. A multiple-pass bulk machining strategy was used to achieve the required dimensions of the channel. The machining parameters were selected based on previous experimental results and the machining was carried out. The channel width and taper were evaluated using optical microscopy. It was found that dimensional and geometrical uniformity can be achieved by multiple pass machining strategy. The channel taper angle was reduced from 8.25 to 0.06 deg. with five-pass machining.

1. Introduction

Miniaturization is the need of the hour. Consumers expect devices of smaller size, increased functionality, and ease of use. This has led to the development of microdevices and MEMS (Micro Electro-Mechanical systems). Micro combustors, microreactors, and micro heat exchangers are a few applications in this regard. Microdevices are also being extensively used in biomedical engineering and biotechnology. Lab-on-chip, microfluidic devices, and drug-delivery systems are a few good examples. The most commonly used geometric feature or entity in all the above-said applications is a microchannel. A microchannel is a miniature feature or a channel with at least one dimension less than 1 mm (Masuzawa & Tonshoff, 1997). Conventional micromachining, namely micro milling was initially used for microchannel making and it had its limitations to the minimum size possible. A few special methods like embossing, etching, LIGA (Lithoformung Galvanoformung Adformung), and electroforming have also been used (Alting et al., 2003). Recent developments in technology led to the usage of unconventional micromachining processes like micro electric discharge machining (μEDM), micro electro-chemical machining (μECM), micro laser machining, etc for the purpose. Micro EDM is widely used among all processes due to its capability to machine a wide range of conductive materials irrespective of their strength. Micro ED milling is a variant of micro EDM where a tool of a simple cross-section, like a cylinder, is fed in a predefined tool path to obtain the desired three-dimensional shape (Jain, 2009).

A study on the influence of energy, tool rotation speed, tool traverse speed/feed rate, and aspect ratio (AR) of the feature on material removal rate (MRR) and tool wear rate (TWR) was conducted. The optimal feed rate was found to be 45 μm/s for the combination of the Tungsten tool and EN24 steel workpiece. Tool rotational speed had the highest influence on MRR, the centrifugal force created by the rotation effectively removed the debris from the spark zone (Karthikeyan et al., 2010). Microfluidic channels were machined on Be-Cu alloy and PMMA (polymethylmethacrylate) material using conventional micro end milling and μED milling. The channels produced by μED milling had lesser burrs and better surface finish. The optimum parametric conditions were used to demonstrate a case study of machining micro-swiss roll combustors (Ali, 2009). Microchannel machining on Inconel 718 alloy was attempted using μED milling. The process was also assisted with low-frequency workpiece vibration to improve the MRR and reduce TWR. The effect of the workpiece

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https://doi.org/10.58368/MTT.22.6.2023.1-6

vibration on the dimensional accuracy and surface quality of the microchannels was also investigated (Unune & Mali, 2020). A simulation of microchannel machining in EN24 steel by µED milling was carried out. The bulk machining approach, where the intended material is removed by a single depth of cut, was studied for the work. The number of passes and the machining time required to achieve the dimensional accuracy of the channels were studied. Microchannels of curved and complex cross-sections were attempted using the bulk machining approach. The parameter conditions were optimized for the straight and curved channels. The effect of the aspect ratio and radius of curvature of the channels on the MRR and TWR was also studied (Shukla et al., 2013).

The materials initially used in the microdevices were plastics, glass, metals, and silicon. Nowadays materials with high hardness and toughness are preferred to withstand harsh and corrosive environments. Metal matrix composites are such advanced materials that are being applied in many fields. An investigation on the machinability of Aluminium metal matrix composites by non-conventional processes like laser cutting, electric discharge machining, and abrasive water jet machining was performed. AA216 containing 20 wt. % SiC and AA356 containing 35 wt. % SiC of average particle size 13 µm was used for the study. The results showed that the SiC particles acted as a shield for the aluminium matrix because of its low thermal conductivity and high melting temperature (Muller & Monaghan, 2000). An attempt was made to optimize blind hole drilling of AA6061/Al_2O_3 composites using tubular electrodes. The output parameters were MRR, TWR, and SR (surface roughness). High MRR was observed with high supply voltage, high peak current, and negative polarity. An increase in injection pressure or rotational speed of the tool also resulted in increased MRR (Wang & Yan, 2000). The machinability of AA6025/SiC composites by rotary tubular electrode EDM was investigated. Brass electrodes with 1.5, 2.5, and 3 mm diameter eccentric holes were used as the tool. The influence of the volume fraction of SiC, polarity, peak current, the diameter of the hole in the electrode, pulse duration, and rotational speed of the electrode on MRR, TWR, and SR was studied (Mohan et al., 2004).

Very few works are available on the micro ED milling of composites. So to explore and understand it, microchannels were machined on AA6063-4 wt. % SiC composite workpiece using µED milling. Multiple pass machining strategy was used to achieve uniform dimensions and profile of the microchannels.

2. Experimental Procedure

The experiments were carried out with a precision micromachining center DT110i supplied by Mikrotools Pvt. Ltd, Singapore. A cylindrical graphite rod having a diameter of 480 µm was used as the tool electrode. AA6063-4 wt. % SiC composite workpiece fabricated by ultrasonic assisted stir casting was used as the workpiece. The electrodes were used in straight polarity conditions i.e the graphite rod was made the negative electrode and the composite workpiece was the positive electrode. EDM oil was used as the dielectric and it was constantly recirculated throughout the process. The tool and workpiece were immersed in the dielectric during machining and the dielectric jet nozzle was also directed toward the machining area. A tungsten carbide block was used as the sacrificial block for BEDG (Block Electric Discharge grinding) to prepare the tool. The electrode polarities were reversed during the tool grinding or preparation. The schematic of the process and the experimental setup used are shown in Fig. 1.

The machining parameters were selected from the previous experiments based on the material removal rate and tool wear rate. The parameters are shown in Table 1. The tool was fed from one side of the workpiece and made to exit through the other side by a bulk machining approach. For the subsequent pass, a freshly prepared tool enters through the exit side of the previous pass and exits through the other side. The image of the tool before and after the slot machining was captured using the on-machine measurement microscope. The microchannel images of the workpiece on both the entry and exit sides were captured using SuXma Met IB optical microscope supplied by Conation Technologies. The width of the microchannels was measured using ImageJ, an image analysis software. The taper angle of the channel was calculated from the entry and exit side width of the channels using the relation in Eq. 1.

$$\propto = (|w_e - w_x|)/l \qquad \text{.............(1)}$$

where α is the taper angle in deg., w_e, w_x, and l are the entry width, exit width, and length of the microchannel respectively.

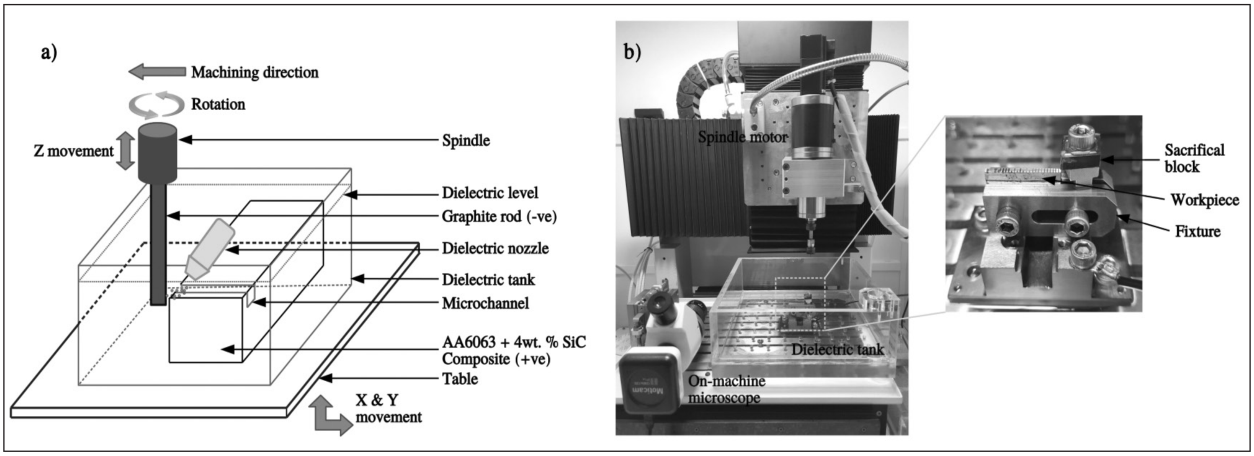

Fig. 1. a) Schematic of the microchannel machining process, b) Experimental setup used for microchannel machining.

Table 1
Parameters used in microchannel machining.

Parameters	Specifications
Positive electrode	Workpiece
Negative electrode	Tool
Tool material	Graphite (ϕ 480 μm)
Workpiece material	AA6063 - 4 wt. % SiC composite (21 x 9 x 2 mm)
Dielectric	EDM 3 oil
Capacitance (nF)	10
Voltage (V)	100
Tool rotation speed (rpm)	500
Tool feed rate (μm/s)	6

3. Results and Discussion

The results of the microchannel machining by micro ED milling are discussed in the following section. Fig. 2. shows the images of the microchannels at the entry and exit sides after machining with different passes. In the first pass, the exit width and depth are very less compared to that of the entry, due to the very high tool wear. In the second pass machining, the side walls of the microchannels were observed to be curved. This was due to the S-shaped wear of the tool. From the third pass, the side walls became parallel, resulting in a regular rectangular cross-section microchannel. By the end of the fifth-pass machining, the entry and exit side widths were almost the same. This indicates the maximum amount of material for the dimensionally accurate channel has been removed.

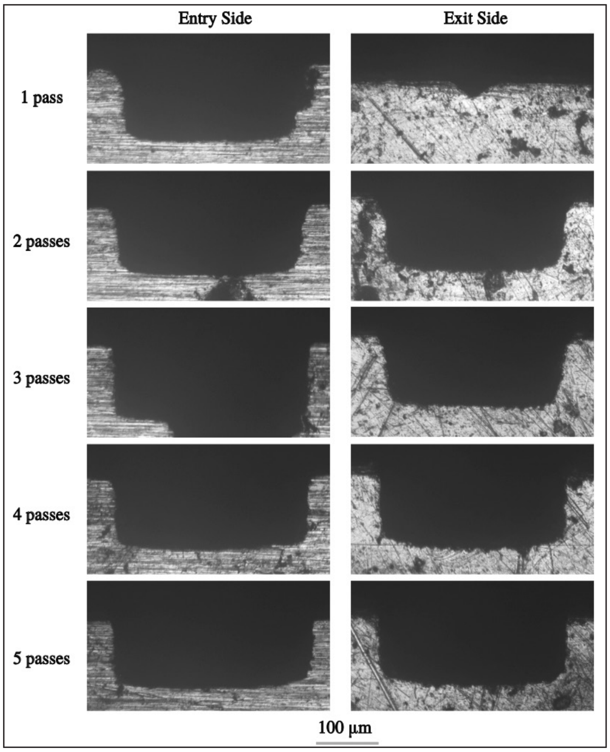

Fig. 2. Entry and exit side images of the channels after multiple pass machining.

The taper of the channels as seen in the top view is shown in Fig. 3. It is observed that the taper is very high in single-pass machining and the channel is almost conical. In two-pass machining, the width at the entry and exit sides had increased but towards the middle of the channel length, the width was very less. From the third pass of machining, the side walls of the channel started becoming parallel to each other indicating a geometrically regular, rectangular channel. At the end of the fifth pass, the microchannel width was uniform and the taper was very minimal.

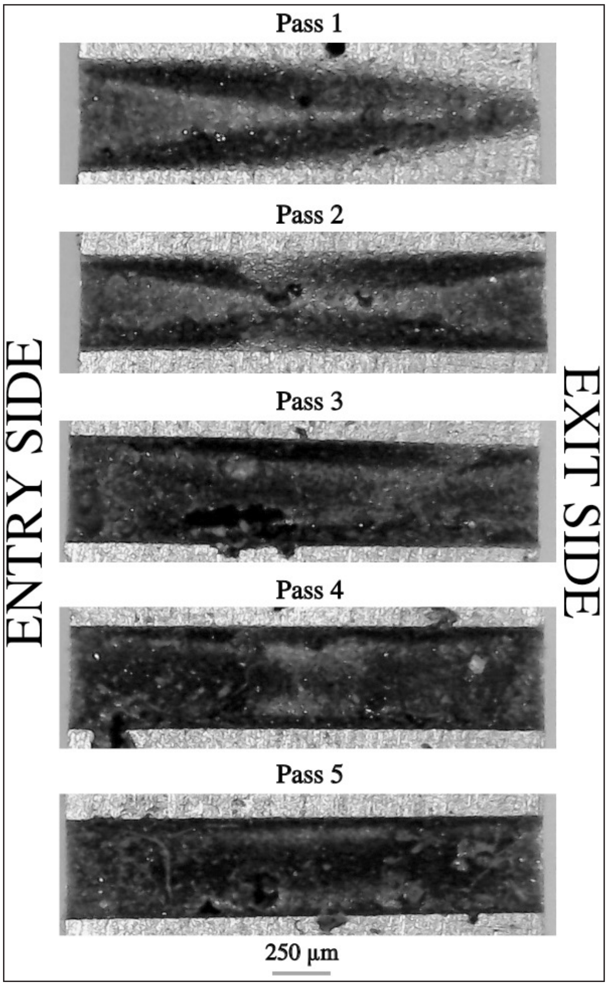

Fig. 3. Top view of the microchannels after multiple pass machining.

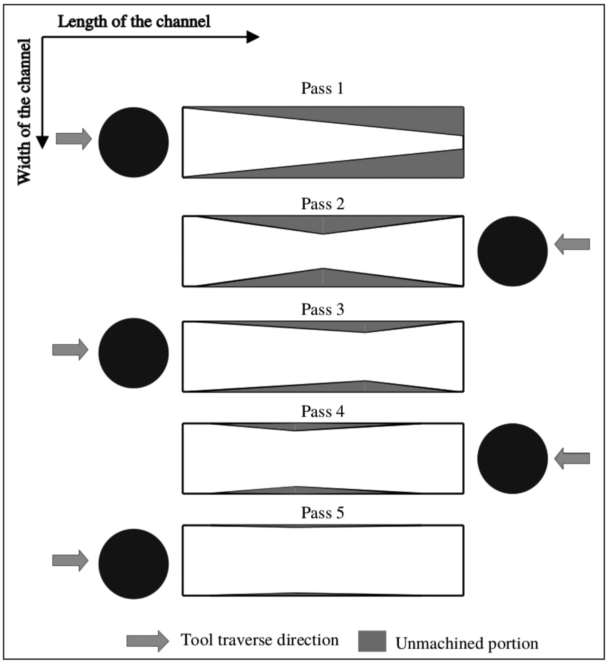

Fig. 4. Schematic of the multiple-pass machining strategy for microchannel machining.

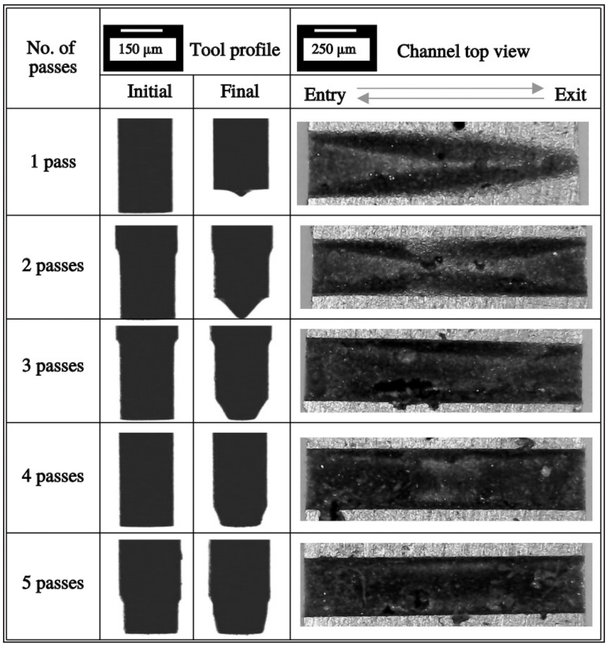

Fig. 5. Tool profile before and after machining and the top view of the channel for every pass of microchannel machining.

Fig. 4 shows the schematic of the multiple passes strategy followed in the microchannel machining process. The tool direction and the amount of material unmachined after each pass is indicated clearly. Fig. 5. shows the profile of the tool before and after machining alongside the top view of the channel with the machining direction of each pass.

The tool wears out during machining and forms a conic cross-section. In the subsequent passes, the conic section broadens out. The maximum tool wear or change in the diameter was observed for the first pass. This was due to a large amount of material available for sparking. With each pass the difference in the diameter of the tool reduces. In the fifth pass, it is evident that the change in diameter is lesser than 15 µm. The unmachined portion of the channel and the tool profile match well. The lesser the tool wear, the more accurate and structurally regular the microchannel obtained. The final tool profile decides the profile of the microchannel obtained. The changes in the entry and exit side widths with the number of passes are shown in Fig. 6. It was observed that the entry width was comparatively larger for the odd-numbered passes and the exit width was larger for even-numbered passes.

This was due to a large amount of material removal on the corresponding side. In the third pass, due to the porosity (as seen in Fig. 3), the tool wear

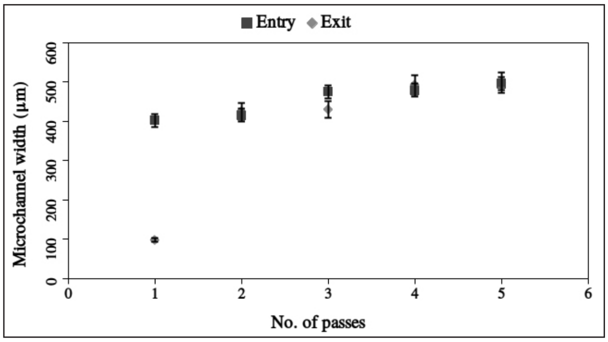

Fig. 6. Effect of the number of machining passes on the entry and exit side width of the microchannels.

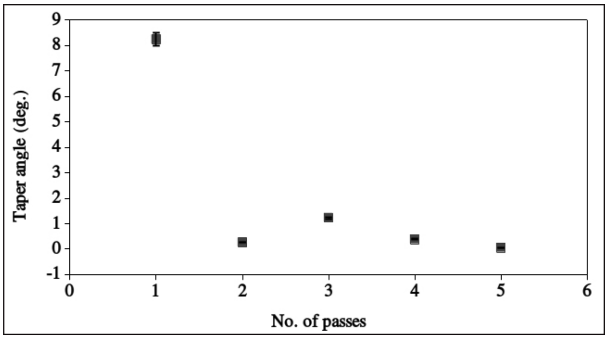

Fig. 7. Effect of the number of machining passes on the taper angle of the microchannels.

was less leading to a higher amount of material removal and a resultant increase in the width. The width values approached each other with an increasing number of passes and in the fifth pass, the difference observed was very less.

The change in the taper angle with the number of machining passes is shown in Fig. 7. The taper angle reduced with an increase in the number of passes. The maximum taper angle of 8.25 deg. was observed for single-pass machining and the minimum taper angle of 0.06 deg. was achieved in five-pass machining. The increase in the taper angle for three-pass machining was due to the porosity present in the path of the channel.

4. Conclusions

Microchannels were successfully machined on the AA6063-4 wt. % SiC composite by micro electric discharge milling process. Multiple passes strategy was followed to obtain dimensionally accurate and regular microchannels. The channel geometrical characteristics like width and taper angle were also measured using microscopic images of the channels.

- The excessive tool wear caused the microchannels to be tapered in single-pass machining.
- There was a 75% reduction in the exit width of the channel when compared to that of the entry in single-pass machining.
- The reduction in width was 2.3, 9.5, 3, and 0.43 % in two, three, four, and five-pass machining respectively.
- The taper angle reduced with an increase in the number of machining passes.
- The maximum and minimum taper angles observed were 8.25 and 0.06 deg. for single and five-pass machining respectively.
- Multiple pass machining with a fresh tool for each pass is a suitable strategy to obtain dimensionally accurate and regular microchannels.

Acknowledgments

The authors are thankful to Central Facility for Materials and Manufacturing Engineering (CFMM) at IIT Palakkad for the support received in using the hybrid micro machining center.

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