Water jet machined thin sheet metal electrodes for micro die-sinking EDM

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Abstract

Microproduction is one of the fastest growing fields of industry with increasing demands from the market. A key factor in microproduction is micro-tooling. There exist various micro-tooling techniques, such as LIGA, electroplating, etc., which are very accurate but on the other hand also very expensive and time consuming. This contribution presents an alternative, which cannot compete with the above-mentioned technologies regarding the accuracy, but is time efficient and far more cost effective. The proposed micro-tooling strategy consists of producing the electrode for Micro Sinking Electrical Discharge Machining (MEDM) using Water Jet (WJ) technology. The final tool is produced by MEDM to be used for replication processes like hot embossing, molding, and others. Results obtained during this investigation indicate the appropriateness of the proposed micro-tooling strategy for the development and design of microfluidic devices, due to the specific characteristics of the involved technologies.

Keywords: Micro-tooling, Water Jet Machining, Micro Sinking Electrical Discharge Machining, EDM, microfluidics

1 Introduction

Recently, the number of products containing microsystems is increasing very fast. Prediction indicates that this market will double over 5 years from 2004 to 2009 [1]. In the late 20th century microproduction was mostly a domain of silicon-based microelectronics, while in the 21st century the demand for micro and nano manufacturing technologies (MNT) capable of processing different materials is emerging [2]. It is therefore evident that existing machining processes has to be adapted and even new ones developed in order to meet the requirements of multi-material microproduction. The main problem is to focus on the right issues for each required part of the design steps and have the available knowledge and technologies. To that extent, both a technology pushed approach and a product/customer driven approach have to be used in order to conduct to a level of knowledge, which can lead to actual production and to bring up a line of future technology research [3].

Microsystems technology is strongly present in the field of biotechnology and medicine. In this respect the fabrication of diagnostic devices is very important due to their role in early discovery of various diseases and effective monitoring of the recovery therapy [4]. Those kinds of devices contain microfluidic features like micro channels, which are suitable to be produced by applying the proposed micro-tooling strategy.

Another very important aspect is the design and development phase of new micro devices. Especially in case of microfluidic applications the possibility of testing is of paramount importance [5]. Therefore, a cost effective prototyping method is of a great help to the microfluidic channel designer, even if prototypes are less accurate compared to the final products.

The proposed micro-tooling strategy is a cost effective method of producing microfluidic devices with accuracy that is still suitable in the design and development phase of new products.

2 Overview Of The Machining Processes Used In The Proposed Micro-Tooling Strategy

2.1 Fabrication of electrodes by WJ machining

Water jetting technology is relatively new machining process developed in the last three decades. The material removal takes place due to erosion of high-speed water jet when impacting on the workpiece. Similar process is an Abrasive Water Jet Machining where abrasive particles are added in the water jet in order to substantially improve the process performance. In this investigation, the WJ was used to produce tool electrodes since a smaller jet diameter can be obtained while keeping the machining performance still acceptable. Note that only small volume of the material have to be removed.

As already anticipated in the early 1980's, manufacturing technologies of the future will have the ability of machining a variety of different materials in an energy effective way. Water jetting technology, especially AWJ machining, is a very flexible process, which can be used for any known material. Additionally, there is almost no heat-affected zone on the machined part.

2.2 Micro-tool machining by MEDM

Electrical Discharge Machining (EDM) is a machining technique through which the surface of a metal workpiece is formed by electrical discharges occurring in the gap between the tool, which serves as an electrode, and the workpiece. The gap is flushed by the third interface element, the dielectric fluid.

The gap width is controlled by the servo system. It is set by the reference voltage and the servo system regulates the gap width in order to make the average voltage in the gap equal to the reference voltage.

The machining process consists of numerous randomly ignited monodischarges. During a discharge, a plasma channel is formed as the current conductor and the heat generator. On the spot of discharge a crater appears. The size of the crater depends on the discharge energy E

$$E = \int_0^{t_e} U(t) \cdot I(t)dt \,, \qquad (1)$$

where t_e is the discharge duration.

The material removal rate (MRR) is determined by the crater size and the frequency of crater generation, i.e. discharge energy and the frequency of discharges. The latter depends on the discharge time and the time between the discharges, i.e. the delay time.

Basically, several EDM processes are distinguished. In micro production, micro EDM milling and micro EDM drilling are most widely used [6]. In MEDM, which is used in the present study, the electrode has a negative shape of the required shape on the workpiece. The accuracy of the electrode shape was directly transferred into the workpiece since the orbital or planetary machining was not used.

3 Proposed Micro-Tooling Strategy

The proposed micro-tooling strategy consists of two steps. In the first step, a copper electrode is produced by WJ machining. Note that water without abrasive was used to machine the copper electrode. In the second step, the final tool is produced by MEDM using the electrode produced in the first step as it is illustrated in Figure 1.

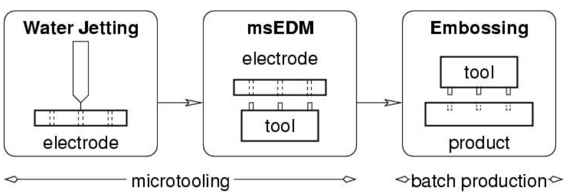

Figure 1: Proposed micro-tooling strategy.

The electrode is machined in a thin copper sheet through which the WJ cuts the desired geometrical features that will appear on the micro-tool.

In contrast to EDM, where electrodes are normally produced by milling or other cutting processes, in MEDM new possibilities of electrode machining are explored, mainly due to the small size of the electrode [7].

Both processes involved in the proposed micro-tooling strategy are further analyzed, where improvements comparing to past investigation [8,9] in this field are presented. The main objective is to combine favorable characteristics of both WJ and MEDM in order to optimize the proposed micro-tooling strategy. Similar approaches are used in other fields, for example micro drilling, where Laser and EDM are combined and advantages of each process contribute to the improvement of the drilling performance [10].

3.1 Previous experience

In previous investigations [8,9], the electrode was machined by WJ in a bulk piece of copper material as shown in Figure 2.

There were several problems related with the bulk electrode. The channels on the electrodes manufactured by WJ were wider than the diameter of the water jet and the width of channel was varying since the water jet had to come out of the electrode as well. Thus, the problems were related with so-called backflow of the jet. Additionally, the MEDM machining time was relatively long and the geometry of the ribs on the tool was not acceptable. Both were the consequences of high debris concentration in the gap, i.e. bad gap flushing conditions.

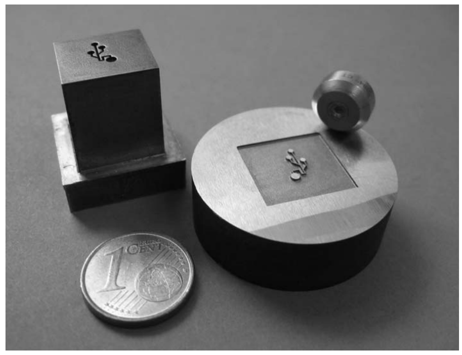

Figure 2: Copper electrode machined by WJ in bulk material and the final tool produced by MEDM.

In the presented study, an electrode was made from a thin copper plate therefore the dielectric fluid could be introduced directly in the gap as shown in Figure 3.

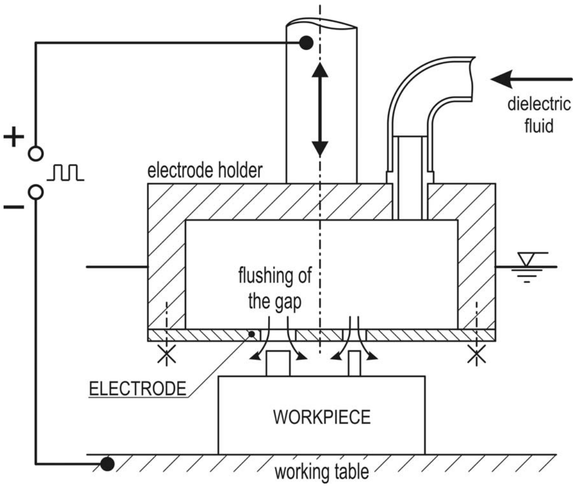

Figure 3: Flushing the gap through a thin sheet electrode.

4 Experimental Work

4.1 Waterjeting of thin cooper sheet

The shape of the feature on micro-tool is given in Figure 4. According to the proposed micro-tooling strategy, the same feature first has to be made on the electrode.

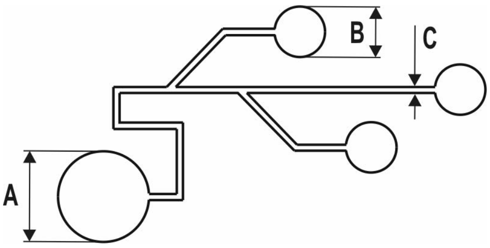

Figure 4: Drawing of the micro feature.

The electrode was made from 0.5 mm sheet copper electrode using WJ cutting technology. The tool, a high speed WJ, was generated in an orifice with the diameter of 100 μm. In the first step, preliminary experiments were carried out to determine the optimal values of the WJ process parameters. The optimization criteria were the accuracy of machined electrode features and the required machining time. According to the experience [9], the following ranges of parameters were used:

- Water pressure *p* from 200 to 300 MPa.
- Cutting velocity *v* from 5 to 15 mm/min.

After optical examination and evaluation of the several features on the electrode, the following conclusions were drawn:

- At higher water pressures and cutting velocities the taper of cut is decreased, but the width of cut is wider.
- The optimal values of setting parameters are *p*=300 MPa, *v*=10 mm/min.
- The beginning and ending of the machining should be placed inside the larger features of the part to avoid increasing in the width of the grooves in those locations.
- The machining time when using the same parameters as in the case of bulk electrode can be even shorter due to the shorter trajectory (In this case you have to cutt only the contour while cutting the bulk electrode you have to use path through the entire surface).

4.2 Micro-tool machining by MEDM using thin cooper sheet

The cooper electrode was mounted on a specially made electrode holder as shown in Figure 5. To manufacture the given feature, the following MEDM machining parameters were used:

- Ignition voltage 180 V.
- Discharge current 2 A.
- Discharge time 8 μs.
- Delay time 36 μs.

Special attention was put on the dielectric flow through the gap. Using higher flow rates causes the machining process unstable, i.e. fast electrode movements to and from the workpiece. A similar phenomenon can be observed in the case of using high surface current density [11].

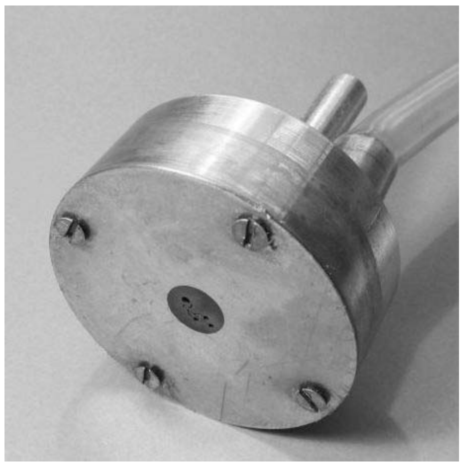

Figure 5: Thin copper sheet electrode.

By using the above machining parameters, the required machining time of the 0.5 mm deep feature on the micro-tool was 3 hours. The feature made on micro-tool is shown in Figure 6.

5 Results

After eroding (3 hrs), measurement points A, B and C on the electrode and micro-tool were measured as shown on Figure 4. The results are given in Table 1.

Table 1: Dimensions of the feature on several machining stages.

Position	New sheet electrode [µm]	Worn sheet electrode [µm]	Steel tool [µm]
A	1400	1420	1360
B	910	940	870
C	130	150	90

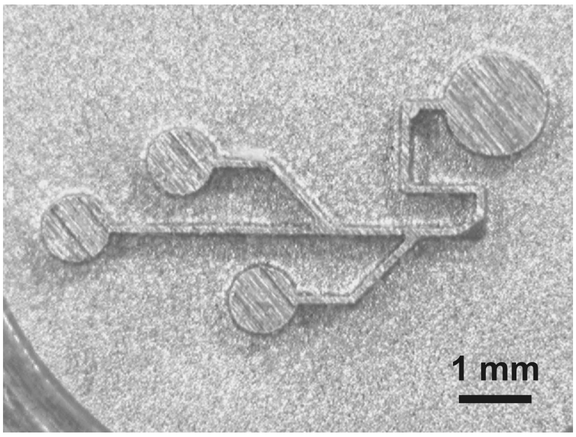

Figure 6: Lab-on-chip steel tool.

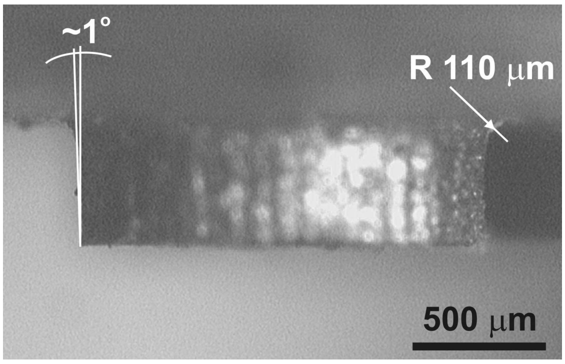

Figure 7: Side view of the micro-tool rib.

The feature dimensions on the electrode after WJ machining are given in the first column. The feature dimensions of the electrode after MEDM-ing are given in the second column. Finally, the feature dimensions on the micro-tool are given in the last column.

The difference between the data in the first and the second column is due to the electrode wear and it varies from 20 to 30 µm. The difference between the data in the second and last column is due to the gap width and it varies from 60 to 70 µm.

The taper of the ribs on micro-tool is 1° and corner radius is 110 µm, both shown in Figure 7.

6 Conclusions And Further Work

The proposed micro-tooling strategy is quick and cost effective. Its main drawback is the accuracy, thus it cannot be widely used in all microfluidic applications. But it can be improved by improving the WJ machining accuracy and to control the electrode wear in MEDM process. Future work will be focused on these two points.

To improve WJ machining accuracy, a more precise x-y axis system should be used to efficiently control the nozzle trajectory. Further on, it is necessary to examine several combinations of various machining parameters, such as nozzle diameter, water pressure and traverse speed and find their influence on the accuracy and repeatability.

Similar should be done on MEDM process where orbital motion could be used to compensate the electrode wear and to produce even smaller features on the micro-tool.

Acknowledgement

This work is supported by the "Multi-Material Micro Manufacture: Technology and Applications (4M)" Network of Excellence, Contract Number NMP2-CT-2004-500274 and by the "Virtual Research Lab for a Knowledge Community in Production (VRL-KCiP)" Network of Excellence, Contract Number NMP2-CT-2004-507487, both within the EU 6th Framework Program.

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