Direct machining of microstructures in polymethyl methacrylate (PMMA) with single-edge micro end mills with diameter 20 µm

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Abstract

The potential of microfluidics has constantly grown over the time. Microfluidic devices are important toolboxes offering a wide range of biological and chemical applications, such as diagnostics, genetic screening and chemistry production. Due to the increase of product variety and reduction in time-to-market, the fast manufacturing of micro structures at a prototype level is desired. This becomes possible through direct micro milling, providing a highly flexible manufacturing process with a high material removal rate.

One challenge in this process is the design of micro end mills limiting the reachable structure size and possible free-form surfaces. In this paper, micro structures are directly milled in polymethyl methacrylate (PMMA) with in-house developed micro ball end mills of 20 µm diameter.

1 Introduction

The manufacturing of microfluidic devices as a single use product leads to developing competitive manufacturing processes such as hot embossing and injection molding. These molding processes allow for mass production of polymer disposables with a low cost per unit [1]. However these methods are for the production of prototype parts very costly and time-consuming. Since designing microfluidic devices is a new engineering discipline and existing fluidic systems in macroscale cannot be simply scaled down, new process for mixing, and also for droplet generation, such as the localized water repellent properties of surfaces, must be studied [2]. Thus aiming to shorten the product development time in a prototype phase, the multi-step fabrication included in the molding process can be replaced by direct milling in polymer, offering a one-step operation directly from the microfluidic structure. This paper describes the overall geometry of a micro end mill and the machinability of possible structures.

2 Micro end mill geometry

Fig. 1 shows how the overall geometry of the micro end mill defines the accessibility for machining. Possible structures may be divided in three types. Type A involves structures where the structure depth is equal or below the tool length (lt). For these structures the aspect ratio (AR) is decisive. Type B structures, where depths are greater than lt , the profile of the neck defines the accessibility for machining. And finally Type C, for structures deeper than ln plus lt , where the critical dimension is the trapezoid angle (αt).

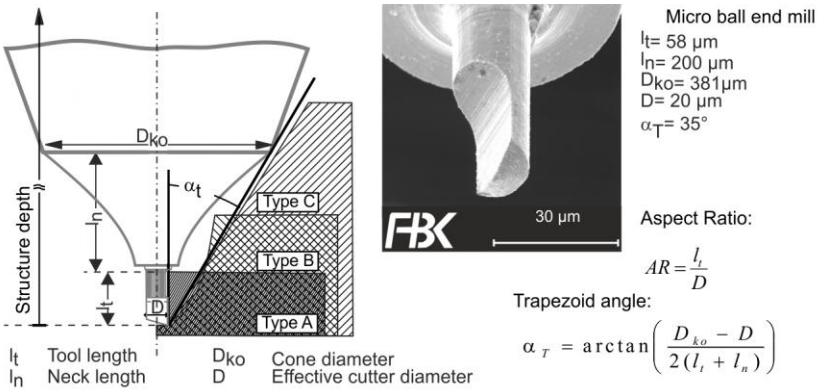

Figure 1: Influence of tool geometry in the accessible structure geometry

Respecting these geometrical relations, micro ball end mills (MBEM), as shown in Fig.1 (SEM image), were used to evaluate the process stability when machining complex 3-D structures. These single-edge tools made of tungsten carbide had a cylindrical cutting section and rounded face with diameter 20 µm.

3 Evaluation

The studies were performed using a CNC 3-axis precision milling machine [3]. For the CAD/CAM interface software package NX7.5 was used. All structures were milled under dry machining and, after milling, ultrasonic cleaning was applied and SEM images were taken.

To evaluate the milling results the structure presented in Fig.2 was machined.

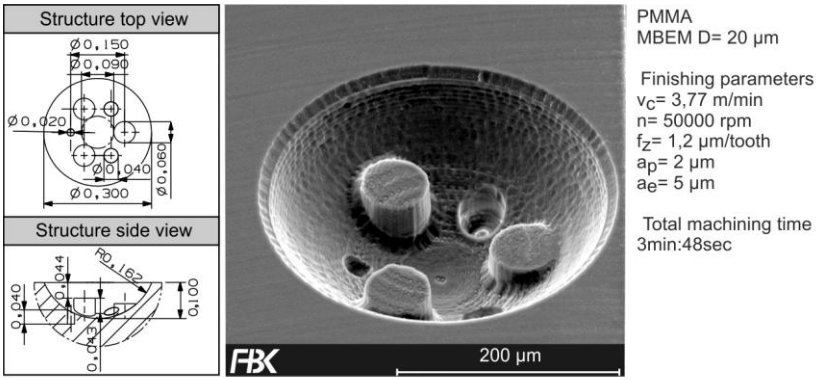

Figure 2: 3-D structure with sharp transitions

This complex structure contains possible features, such as holes, contoured shapes and sharp edge transitions. To assess the simultaneous movements in the X-Y-Z direction, a spiral contoured tool path was applied and the structure was completely machined, with no tool changes. The SEM image shows good feasibility using MBEM even when machining sharp edge transitions, such as those presented in the columns.

Finally a structure similar to the lotus leaf surface was machined (Fig.3) to evaluate the micro structuring of surfaces.

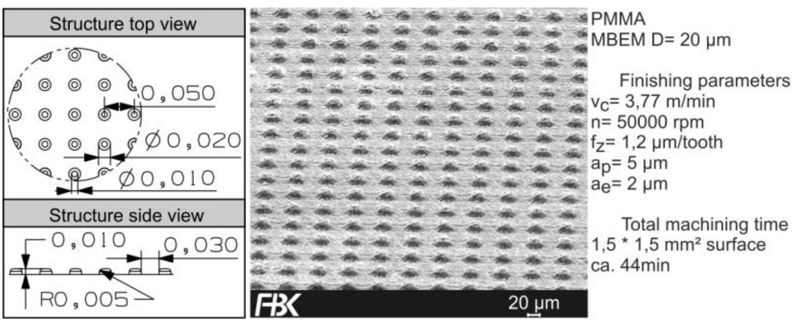

Figure 3: Machined structure based on the lotus leaf surface

Despite the sensitive up and down drive of the Z axis while the X axis moves, it was possible to structure the surface showing high process stability with minimal remaining burrs. Different than other manufacturing processes, the degree of abstraction can be minimized and even position and height of each column is able to be adjusted.

4 Conclusion and Outlook

The direct milling of structures in PMMA with micro tools- diameter 20 µm - is a viable method to produce free-forms used in microfluidic devices.

The chosen strategies and micro ball end mills allow the machining of complex structures, with contoured shapes and sharp edge transitions with minimal remaining burrs, and it represents a competitive process in a prototyping level by reducing time to market. Further research will measure the hydrophobic properties of milled structures.

5 Acknowledgement

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