Optimizing Hot Embossing of Poly(methyl methacrylate) Microfluidic Chip

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Abstract

Microfluidic research become a more important research field in mechanical and bioengineering fields. The application of microfluidic positively relates to the ability to manufacture micro or precision. Nowadays, the manufacturing in this area is aimed at around 100-500 µm. Here, a hot embossing method is reported to realize microchannel with height and width dimensions of 150-300 µm and 600-800 µm, respectively. This study also shows that the margin factor between the mould/dies to the realized dimension is 50-70% and 5-7% for height and width, respectively.

Keywords: Microfluidic, micromanufacturing, microchannel, hot embossing

1. Introduction

A microfluidic chip is a pattern of microchannels molded or engraved. This network of microchannels incorporated into the microfluidic chip is linked up to the macro-environment. Fluids are directed, mixed, separated, or manipulated to attain multiplexing, automation, and high-throughput systems [1]. The microchannel network design must be precisely elaborated to achieve the desired features (cell culture, electrophoresis, molecular analysis etc.) [2-4]. Some basic microfluidic structures are channels, chambers/cavities, and pillars. Failure to provide suitable channel dimensions could potentially inhibit the performance and thus limit the success of a lab-on-a- chip device. Whilst the physical features on a chip are designed to enable or enhance the functionality of processes, their fabrication is essentially through the application of engineering methods.

As commonly use in medical pathology diagnostics is using glass material, while wide range rigid polymers such as acrylics, polypropylene, and polystyrene are also common in containing the specimen, due to its transparent properties (good optical transparency) and leakproof characteristic. Glass material is highly brittle compared to more ductile polymer material, especially the most common type of glass. The brittleness may expose the specimen, therefore contaminating it when stress is applied to the platform, for example, it drops. Fulfilling all the criteria, poly-methyl methacrylate (PMMA) is the selected material for the microfluidic chip used in this research.

There are several ways to manufacture processing of the PMMA material into the desired microfluidic chip platform. The manufacturing processes include polymer casting, 3D Print, micro milling, injection moulding, thermoforming and hot embossing [5]. The polymer casting process takes relatively longer to be in a mass production cycle. Moreover, precise geometry cannot be achieved for a dimension of less than 1 mm of microfluidic chip. Likewise, 3D printing is an effective option for low-volume production because no mold is necessary. Recent studies found that the result is limited due the using of nozzle diameter that around 1mm at this moment.

On the other hand, direct micro-milling gives straightforward results and establishes correct machining parameters. Removal of material through milling can lead to a redistribution of the internal stresses in the polymer piece, leading to a warping piece and potentially altering the dimensions of fabricated specimen using this method. The laser engraver forms the channel with repeatable passes. The mass production of microfluidic chip is unsuitable with this process as long time.

Injection molding is most typically used in the mass-production process in scale of thousands or even millions of specimens. Small features, such as sub-microns, are possible due to the high resolution that can be achieved through a metal mold. However, production through this fabrication method can be complicated by molding parameters such as polymer temperature, mold temperature, injection pressure or speed, shot size, and cooling time. Material conditions must also remain consistent since contaminations such as moisture can negatively impact device quality (usually delamination of the material).

Thermoforming has the advantages of flexible design, rapid prototype development, high production rate, low set-up cost, and less thermal stress. On the other hand, disadvantages are not eligible for thermosets, all parts need to be trimmed. The most suitable process is compression or mechanical forming since it can fulfil the complex geometry of the microfluidic chip design.

Rather than melting the material being forced into a mold, hot embossing stamps a work piece, thus imprinting the features onto the polymer. Heat and applied load are required to be effective and must be determined by the Mold and polymer to ensure features are accurately reproduced. [6]. At glance, hot embossing is similar to the thermoforming mechanism, but the research is limited to a thin work piece lower than 1 mm of sheet. Since the required wall thickness of the microfluidic chip is 3 mm, it is most feasible to use the hot embossing. The challenge is to determine the parameters for this method to produce a uniform thickness with no defects.

2. Methods

Microfluidic Chip Design

The microfluidic chip was designed using Computer Aided Design (CAD) SolidWorks software (Dassault Systemes, France). The design is shown in Figure 1.

Mold Fabrication

The Mold is fabricated with milling process using CNC milling machine: Kamioka, VMC-1000 Series. Before the machining process with CNC, a simulation is needed to evaluate the mechanism of the tool path. CAM (Computer-Aided Manufacturing) software is Mastercam X7. The G-Code and M-Code (as shown in the Appendix 1 and Appendix 2) is generated by CIMCO Edit v5 software, as translated command with post processor program to be read by motor controller and machine..

Microfluidic Chip Hot Embossing

Pre-cut PMMA material is placed into heated mold cavity. The Mold is directly closed with a top plug (mold core) and pressure is applied (using C-clamp) to force the material to contact all areas of the Mold. Throughout the process heat and pressure are maintained until the PMMA has cured.

The heating mechanism of the Mold were conduction and convection modes. In the first mode, the Mold placed on the electrical heating pad for 30 minutes with the clamped during embossing. The molding temperature varied in 80°C, 90°C, and 100°C. The second mode, convection heating, the Mold placed in oven until the Mold reaches temperature of 60, 80 and 100.

The cooling of the Mold by using natural cooling to reaches room temperature. This leaves the Mold to have less bending of the product.

Contour Measurement

Resulted microchannel was measured using a direct contact stylus method from Surfcom 2900SD3.

3. Results and Discussion

The design of microchannel taken from our previous work that relates with thermocycler for polymerase chain reaction as shown in figure 1a. Figure 1a also shows a height of 0.5 mm and 0.75 mm channel width. The total length was corelate with the flow and volume of liquid sample that was being handled.

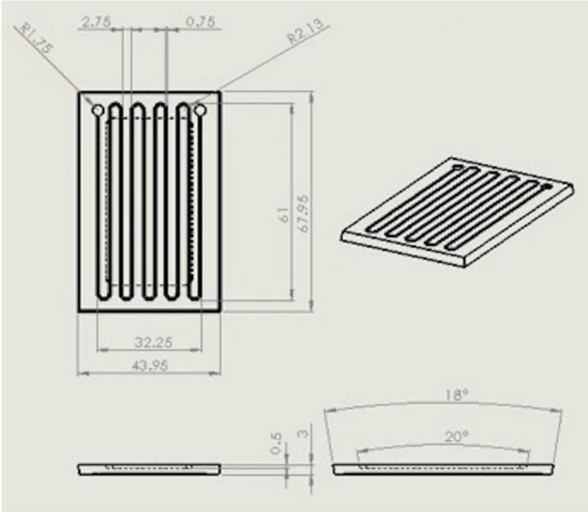

Figure 1. The design of microfluidic chip

Figure 2 shows the design of mold cavity to realize the desired microchannel. This Mold acted as dies in the embossing process. The shrinkage factor that input in the design was set at around 7% for aluminum.

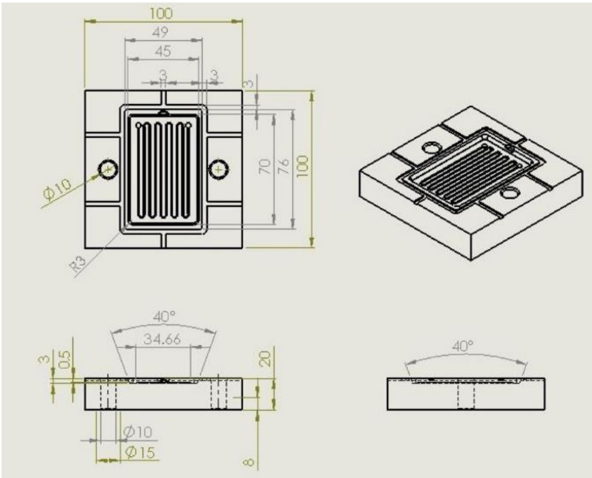

Figure 2. The design of mold cavity for pre-designed of microchannel chip.

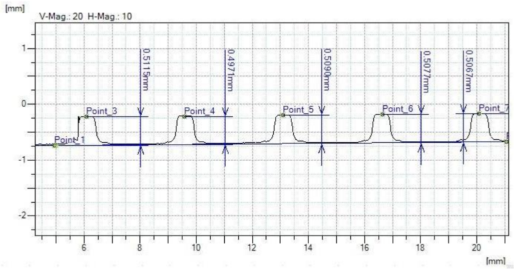

Figure 3. Realized embossed dies of microchannel and the result of contour measurement.

Figure 3 is realized embossed dies using the method as explained. The geometry of the mold cavity was confirmed by the contour measurement using Surfcom 2900SD3. This contour was equipped with an instrument detector acquired in a computer software of ACCTee Mesurement. The ACCTee enable us to analyze resulted data. Measurement was done by scanning the Mold from the center to side of the peripheral length (figure 3a). The contour was shown in figure 4b which resulted in 0.505±0.008 mm height and 0.720±0.063 mm width. This figure reflects that the margin between realized to design is 1% and 4% for height and width, respectively.

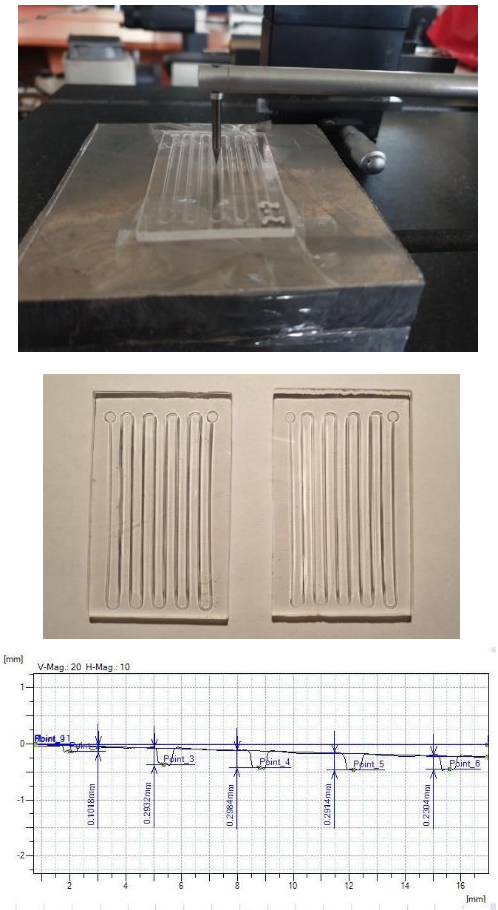

Figure 4. Realized PMMA microchannel and resulted geometrical dimension.

The contour measurement of microfluidic is shown in figure 4a. The result was shown in figure 4b with 0.250±0.033 mm height and 0.684±0.127 mm width. Compared to the geometrical design, the margin was at 50.5% and 5% for the realized height and width, respectively.

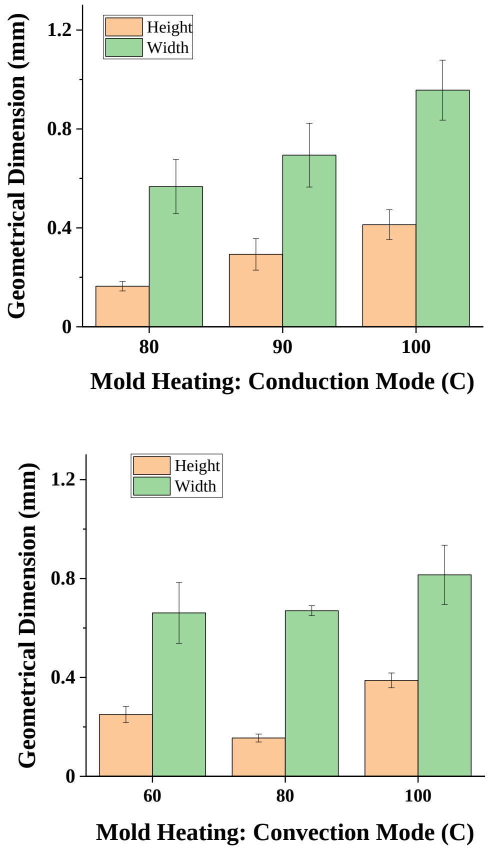

Figure 5. Realized embossed dies of microchannel and the result of contour measurement.

Figure 5 shows the detail of optimizing temperature of heating both for conduction and convection modes. The study shows that the heating embossing temperature affects the dimension of microchannel. The height and width of the designed microchannel was relatively achieved at around 100°C although has a high standard deviation.

Figure 5 also suggests that the smallest standard deviation was at convection heating mode at the temperature of 80°C. Note that the glass transition temperature of PMMA is at around 85-105°C. Our observation also explained that the measurement in the heating mold is deviate at around 15°C. This heating temperature indicated that this condition reaches the molecular movement of the PMMA. Moreover, the convection mode also contributes in more uniform heating. This heating mode and temperature can be concluded as the optimum embossing temperature. The gap between designed to realized height and width are 69% and 7%, respectively.

4. Conclusion

The realization of microchannel using hot embossing method was performed in this report. The embossing temperature acted as a significant parameter which need to be optimized. Theoritically, the PMMA was able to be formed at its glass transition temperature. However, the heating modes also reported an important parameter. The convection heating gives the small deviation of dimension compared to the conduction mode.

Daftar Pustaka

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