

Numerical study on fabricating rectangle microchannel in microfluidic chips by glass molding process

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Abstract. This paper studied the glass molding process (GMP) for fabricating a typical microstructure of glass microfluidic chips, i. e., rectangle microchannel, on soda-lime glass by finite element method. More than 100 models were established on the platform of Abaqus/Standard. The influence of parameters, i. e., temperature, aspect ratio, side wall angle and friction coefficient on deformation were studied, and the predicted morphology of the molded microchannel were presented as well. The research could provide fundamental experience for optimizing GMP process in the future.

1. Introduction

Due to potential advantages in chemical and biomedical testing, microfluidic devices have drawn great attentions among academic and engineering communities [1]. Different kind of microfluidic devices were fabricated for wide applications, such as capillary electrophoresis [2-3], semen testing [4], electrochromatography [5] and DNA separation [6].

There are many substrate materials for fabricating microfluidic chips, such as silicon, Polydimethylsiloxane (PDMS), polymethyl methacrylate (PMMA) and glass. Among them, glass has many advantages over other materials, such as excellent optical properties, good insulating properties, high resistance to mechanical stress, high surface stability, and high solvent compatibility [7].

In order to achieve the widespread application of glass microfluidic chips, many researchers have been exploring the field of microstructure fabrication techniques in glass, and the conventional approaches can be classified into four categories: wet etching, dry etching, laser processing and mechanical processing [8]. However, the majority of conventional approaches suffer from low efficiency, high cost, poor surface quality and environmental pollution, which impede the widespread application of glass applications substantially.

Since rectangular cross-section microchannel is a fundamental structure of microfluidic devices, exploring glass molding process (GMP) to machine the microstructure is important to practical applications. This paper aims to investigate the formation process of rectangular cross-section microchannel in GMP by simulations. More than 100 models were established to study the influence of molding parameters, i. e., temperature, aspect ratio, side wall angle and friction coefficient on the mold shaped. The research could provide fundamental experience for optimizing parameters in machining rectangle microchannel on soda-lime glass in the future research.



2. Modelling process

In terms of the glass preform material, since the soda-lime glass slides have been used by biomedical researchers to conduct experiments for decades, and it is inexpensive which can help reduce the whole fabrication cost, it is utilized as the preform materials in the paper. The physical properties of soda-lime preform are referred to [9]. According to [10], the appropriate model temperature is 620°C , the range of temperature studied in the simulation is between 610 and 660°C .

All the simulation models are established in the commercial finite element software Abaqus/Standard. Since the molding speed is relatively slow compared to other machining process, the GMP process is regarded as a quasi-static process. The GMP process consists of four stages, i.e., heating, pressing, annealing and cooling, as shown in figure 1. In this paper, the only pressing stage is simulated, and all the molds and preform are assumed to maintain a constant temperature, which is tens of degrees centigrade above its transition temperature.

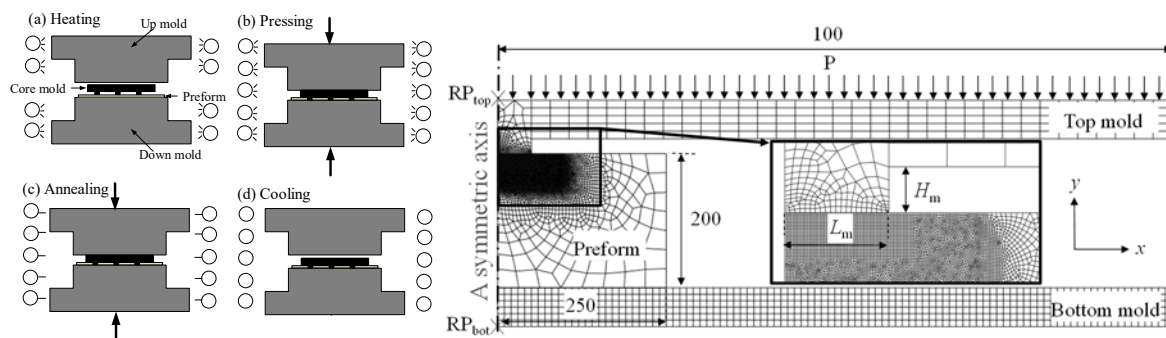


Figure 1. The GMP cycle **Figure 2.** The established model for GMP process

At the pressing condition, the preform demonstrates high viscoelasticity, which is a time-dependent response of a material to stress or strain, and they are characterized by creep and stress relaxation behavior. In this paper, a 6-pair generalized Maxwell model is used as the constitutive model, and the specific parameters are referred to [9]. As shown in figure 2, a rectangle specimen geometry of preform with $200\mu\text{m}$ height and $250\mu\text{m}$ width are established in the model, and it is placed on a rigid platen which is control by a reference point RP_{bot} . All the freedoms of RP_{bot} are constraint. A rigid platen with a micro-protrusion below is built as the top mold which is controlled by a reference point RP_{top} , and all of RP_{top} freedoms are constraint except for y direction. The height of the micro-protrusion keeps as $22\mu\text{m}$ in all the simulations. Due to the axisymmetric structure, only half of the model is built for simplicity, and the X-symmetric boundary condition is set on the left edge of preform. A uniform distributing pressure 0.2MPa is applied on the top mold. In order to alleviate the mesh distortion during pressing process, the meshes near the protrusion are densified. All contact behavior are described by the classic Coulomb friction model.

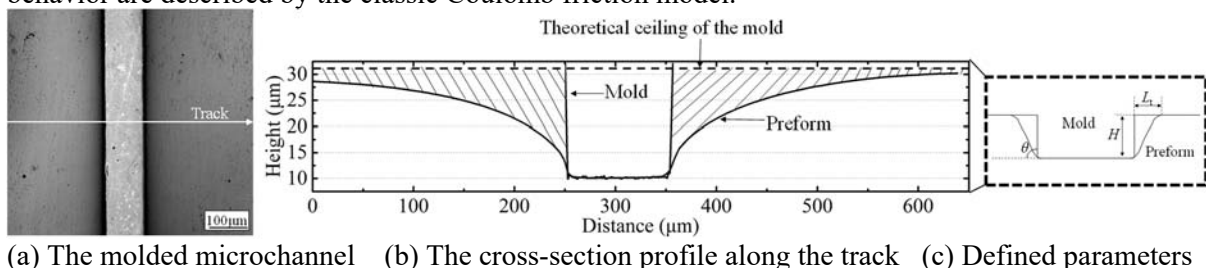


Figure 3. A typical molded glass microchannel in experiment

Figure 3 shows a typical molded glass microchannel in experiemnt. Figure 3(a) is the actual molded microchannel obtained by Olympus Lext OLS4100, and the surface quality of the molded

microchannel appears to be smooth. The cross-section profile of the microchannel is extracted along the track, and shown in figure 3(b), and it indicates that there is large area between the mold ceiling and preform, which is marked by dash area, not filled. In order to quantitatively study the influence of molding parameters on the molded morphology, the two characteristic parameter, i.e., H and L_t , are defined based on the typical deformation process, and they are shown in figure 3(c). L_t represents the distance from the side wall of core mold to the point where the preform and mold ceiling starts to separate. H stands for the height of the protrusion. Since all the height in the simulation is fixed at $22\mu\text{m}$, a deformation factor D , which is equal to L_t divided by H , is utilized as predicted results from the simulation models. The smaller the D value, the better the shape transferability. As the glass preform is pressed at the same temperature, no heat transfer is considered in this simulation.

3. Results

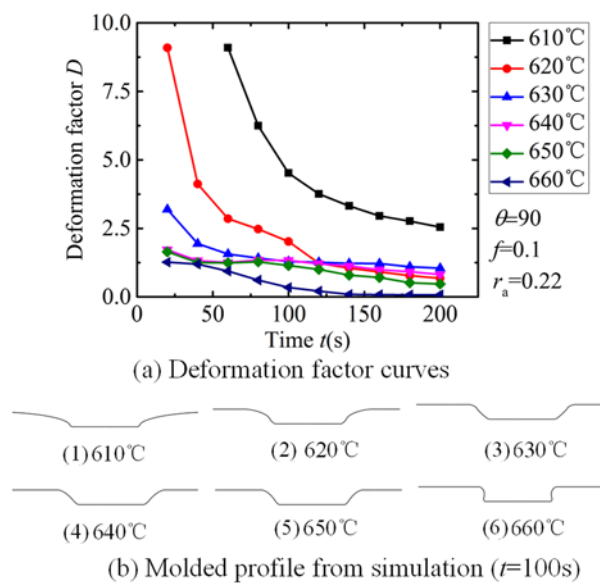


Figure 4. The effect of temperature (100s)

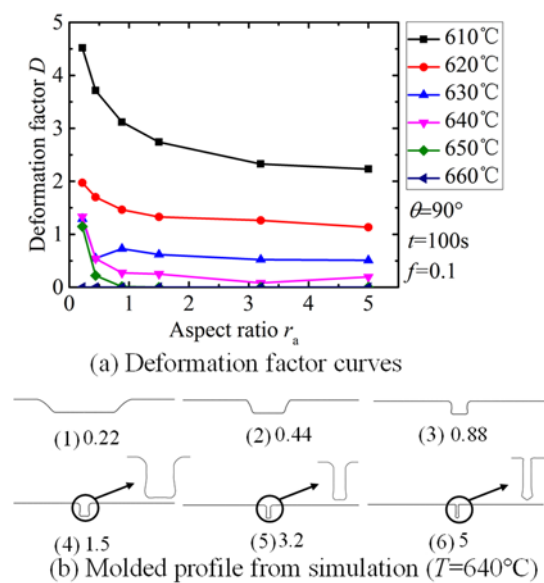


Figure 5. The effect of aspect ratio

The effect of temperature on deformation is shown in figure 4. Figure 4(a) demonstrates that the deformation factor D decreases dramatically with pressing time below 100s, and as time goes further, a slow drop of D is witnessed. It can be attributed to the glass characteristic of stress relaxation and creep under high temperature molding process. As for temperature, it is observed that D reduces with temperature as well. It is worth pointing out that it is possible to achieve almost full shape transferability when temperature is set at 660°C and the pressing time is above 140s. In order to provide more information about the predicted shape, only the top profiles under six different temperature at 100s are extracted, as shown in figure 4(b). It confirms that high shape transferability can be achieved at high temperature.

The effect of aspect ratio on deformation factor is shown in figure 5. The horizontal axis is aspect ratio instead of pressing time, which means that each point is based on a single simulation test. D decreases dramatically when aspect ratio increases from 0.22 to 0.88; while when it increases further, a slight drop of D is witnessed. Since the height of the protrusion on the mold is fixed, the large aspect ratio represents small width of the protrusion. When aspect ratio is larger, less portion of material is supposed to experience deformation, thereby making the filling easier. As for temperature, D reduces with the increase of temperature as well. It is interesting to find that almost full shape transferability occur at both curve 650 and 660°C when aspect ratio is equal or about 0.88. The profiles of molded

shape at different aspect ratio are shown in figure 5(b). It indicates that the higher the aspect ratio, the smaller the D . According to figure 5(b6), the almost right angle can be achieved.

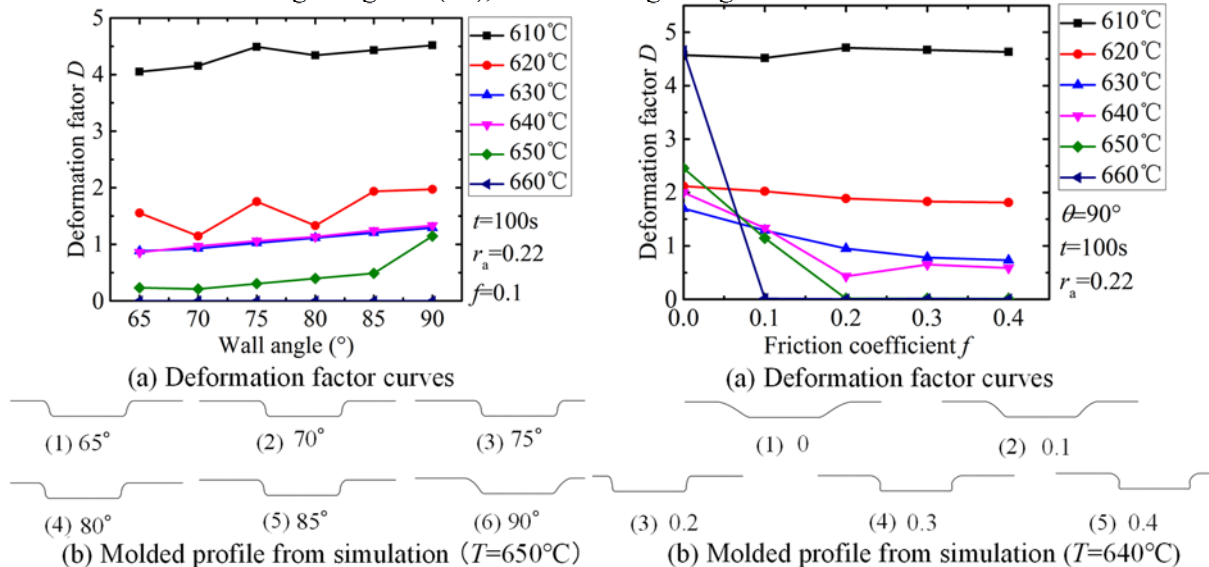


Figure 6. The effect of side wall angle

Figure 7. The effect of friction coefficient

The effect of side wall angle on deformation factor D is shown in figure 6. The influence of side wall angle on D is not significant compared with those of pressing time and aspect ratio, although a slight increasing pattern is witnessed. It can be attributed to the fact that the larger angle is supposed to make the deformation process more difficult, thereby reducing the shape transferability and increasing deformation factor D . The 660°C curve can achieve almost full shape transferability at all investigated pressing condition. The profiles of molded shape at different angles are shown in figure 6(b). It is confirmed that the higher the side wall angle, the higher the D value.

The influence of friction coefficient on deformation factor D is shown in figure 9. It is interesting to find that the influence of friction coefficient on D is negligible when temperature is at 610 and 620°C, and its influence becomes increasingly significant as temperature increases further. Especially, D decreases from 4.6 to around 0 when friction coefficient increases from 0 to 0.1 at 660°C. It indicates that the temperature and friction have interactive influence on D . When temperature is higher, the preform is easier to deform which increases the influence of friction coefficient greatly. In addition, higher friction coefficient makes the deformation of preform harder along horizontal direction, which in the end leads to higher shape transferability. The profiles of molded shape at different angles are shown in figure 9(b). It is confirmed that the higher the friction coefficient, the smaller the D .

4. Conclusions

(1) The deformation factor D decreased dramatically with pressing time below 100s, and as time went further, a slow drop of D was witnessed. The deformation factor D decreased significantly when molding temperature increased.

(2) The deformation factor D decreased dramatically when aspect ratio increase from 0.22 to 0.88; while when it increases further, a slight drop of D is experienced.

(3) The influence of side wall angle on D is not significant compared with those of pressing time and aspect ratio, although a slight increasing pattern is witnessed. In addition, the temperature and friction coefficient had obvious interactive influence on D .

Acknowledgements

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