등온압축성형공법을 이용한 폴리머 렌즈 성형

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Isothermal Compression Molding for a Polymer Optical Lens

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Abstract

Aspheric polymer lens fabrication using isothermal compression molding is presented in this paper. Due to increasing definition of an image sensor, higher precision is required by a lens which can be used as a part of an image-forming optical module. Injection molding is a factory standard method for a polymer optical lens. But achievable precision using injection molding has a formidable limitation due to the machining of complex mold structure and melting and cooling down a polymer melt under high pressure condition during forming process. To overcome the precision requirement and limitation using injection molding method, isothermal compression molding is applied to fabrication of a polymer optical lens. The fabrication condition is determined by numerical simulations of temperature distribution and given material properties. Under the found condition, the lens having a high precision can successfully be reproduced and does not show birefringence which results often in optical degradation

1. Introduction

Since the definition of a color image sensor has been being increased continuously and the size of a pixel is reduced under 1.4 μm, there are tremendous needs to fabricate high precision optical lens. Typically, the allowed tolerance goes down under 0.3 μm for shape difference between the optical design and the molded lens.

A factory-standard method for forming a polymer lens is injection molding which gives an acceptable precision and is well-suited for the mass production. However, injection molding has a formidable limitation in increasing the precision due to the machining of complex mold parts and melting and rapid cooling down a polymer melt under high pressure condition. Slight imbalance in a fabrication process results easily in loss of precision and the tolerance of the product does not allow such a precision loss.

To overcome the present tighten-up situation, isothermal compression molding is considered as a fabrication method. The isothermal compression molding is an old-fashioned method to process a polymer and called by various names with respect to applications like hot embossing or stamping for microsturctured parts, imprinting for nanoscsale structured parts, and thermal press for metal parts, and so on. (Heckele & Schomburg, 2004; Shift et. al. 2001) The compression molding was recently used for a glass lens using a low melting temperature glass gob and successfully applied to a miniaturized camera module. (Umetani, 1998; Chang et.

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al. 2007) Also, remelting molding technique is proposed by Koseko et. al. (2000) and the surface replication process of the technique uses an isothermal compression and is successfully applied to an aspheric f-theta mirror

Isothermal compression molding process for thermoplastic polymer comprises of: (i) preform prepared and inserted into the mold; (ii) heating the preform above certain softening temperature; (iii) pressing with moderate force and then; (iv) cooling down the mold insert and removing the replicated part from the mold. Therefore, the polymer is processed in a low temperature around the glass transition temperature and flows only inside the mold cavity. As a result, very small amount of stress is produced during the process comparing with injection molding. The flow stress and restructuring stress result in birefringence and degrade the optical properties of the molded structures. (Lee et. al. 2002) Also, due to low temperature, isothermal compression molding reduces the shrinkage in cooling process and friction forces for demolding. Since mold tools and machines for isothermal compression mold are also simple in contrast to injection molding it can have an advantage in reconstruction, modification and reduced assembly precision loss.

In this paper, new optical lens fabrication process based on isothermal compression molding is proposed and procedures to determining the process parameters are discussed. Also, the quality of molded lens is discussed comparing with lens obtained by injection molding.

2. Experimental Setup

Before the lens forming is conducted, the preform should be prepared. The preform is fabricated by rough molding and polishing for the diameter of the preform to be equivalent to the volume of the lens. The tolerance is set to be equivalent to that of the lens. An optical grade polycarbonate resin (SP1516, Teijin, Japan) is used for the spherical preform which is grinded and lapped to have 2.544±0.005 mm in diameter. The surface roughness of preform is about 10um. The mold consists of the upper and lower cores on which the lens shapes are machined and the bush to guide the cores. Tempered steel (STD11) is used for all mold components which is same as mold components for injection molding. Electroless nickel is plated on the top of mold surface after rough machining the mold surface. By using the ultraprecision machine (ASP30X, Nachi, Japan), the mold is finished to have a designed lens shape.

Figure 2 shows schematics of the molded lens which have a meniscus concave type profile. The optical design uses the aspheric equation and is for a 5 megapixel, 1/4 inch sensor. The outer diameter is 4.7 mm and two effective diameters are 2.185 mm and 2.774 mm, respectively. The height of lens is 1.003 mm and the thickness of the lens on the optical axis is 0.42 mm (thinnest).

The aspheric lens is molded on a progressive press machine (Sys Co., Japan) which use pneumatic compression (Max. 0.9MPa pressure difference). The press machine have six stages consisted of three preheating stages, a main press (forming stage), and two cooling stages.

3. Determination of process parameters

Focusing on the forming stage condition, heating temperature, main press pressure and residence time on each stage are chosen as control parameters. To determine the heating temperature, fixing the residence time, 120 sec. on each stage and the compression force about 100N (calculated based on the surface area of the core and pneumatic pressure), the temperature is increased stepwise by 10°C based on the glass transition temperature (Tg=151°C for the present resin). The sufficient deformation can be achieved between 190°C and 210°C. Above 210°C, local flaws due to rapid melting and trapped gas are observed. Comparing to the remelting molding technique (Koseko et. al. 2000) which uses Tg+10°C and 50MPa, increased temperature in present method reduces the compression pressure. On the core surface, electroless nickel is plated for diamond tunning. Reduction in compression force increase mold life time and affects positively on overall accuracy of the molded part.

The residence time is determined by the numerical simulation of temperature using a commercial package (COMSOL Multiphysics) at the preheating stage where the longest residence time is expected. The side wall is forced to have adiabatic condition and upper and lower wall is set to constant temperature, 200°C. The initial temperature of mold component is set to 20°C and the gas to 100°C. In addition, it is assumed that there is no gap between the mold components. Figure 3 shows temperature evolution at the center of the preform and temperature contour after 120 seconds. After 120 seconds, the temperature at the center of the preform reaches Tg+20°C at which normal the resin begins to have fluidity. Therefore, the residence time at each stage is set to 40 seconds.

By changing compression force, about 50 to 200N, we observed the status of molded products and did not find any discernable difference with respect to the compression force. It is worth to be note when rate of compression (vertical rate of deformation) is not exceeded 0.1 mm/sec, we can obtain appropriate results. Therefore, it is set to about 100N.

4. Discussion

Figure 4 shows a molded lens by the hot press and birefringence image. As expected due to low flow rate and melting temperature, excellent performance against birefringence is shown. The lens profile is measured with horizontal, vertical and 45° oblique directions to show excellent axisymmetry of the molded lens (figure 5). Lens profile is measured with a profilometer (PGI 1240, Taylor Hobson, England). The profiles of the lens show excellent agreement within 0.1 μm among each other. It means that flow friction during the forming stage and shrinkage in cooling down does not break the symmetry of the molded lens. Also, the profile difference between the optical design and the mold lens are compared and depicted on the figure 6. The peak value (PV) of form difference shows only 0.167 μm. This value is obtained after correcting the lens profile based on the difference between the design and molded one. The surface data presented in this paper is the upper part of the lens. The lower part reveals much larger values in PV about 3 μm due to misalignment of the two lens cores and inaccurate perpendicularity of the bush.

5. Concluding remarks

As a new forming method of the polymer lens for a miniaturized camera, isothermal compression molding method is introduced. The mold parts are precision machined and preform is prepared based on the volume of the molded lens. The process conditions are determined based on the parameter study and the numerical simulation. The heating temperature should be above the Tg+40°C for proper molding. Based on the simulated temperature at the center of preform, the residence time is determined. Since the force needed for forming is very small and the process time is determined by the preheating stage, there is no discernable difference with respect to the compression force. In the determined conditions, the lens is molded and shows excellent performance.

Figure 1. Photos of the mold components: upper lens core, lower lens core and bush (from left to right) and assembled mold

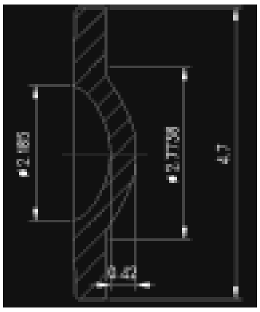

Figure 2. Schematics of the lens design

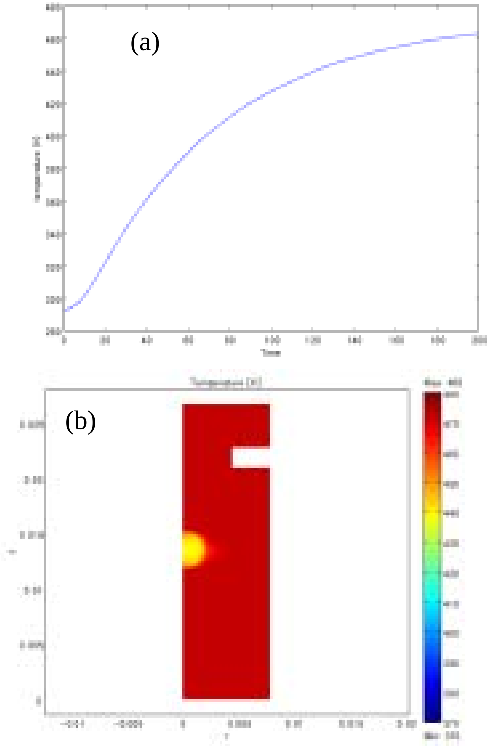

Figure 3. Temperature simulation results: (a) Temperature evolution at the center of the preform; (b) Temperature profile after 120 seconds

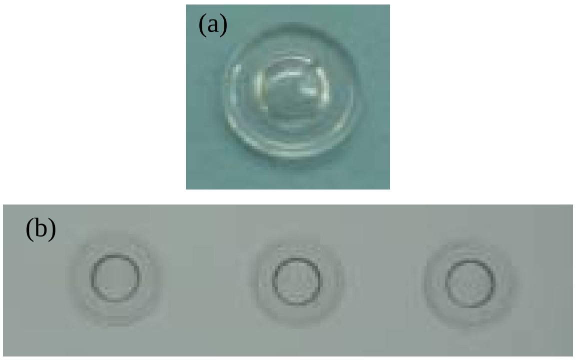

Figure 4. photos of molded lens: (a) plan view; (b) view within two polarized lens to show birefringence

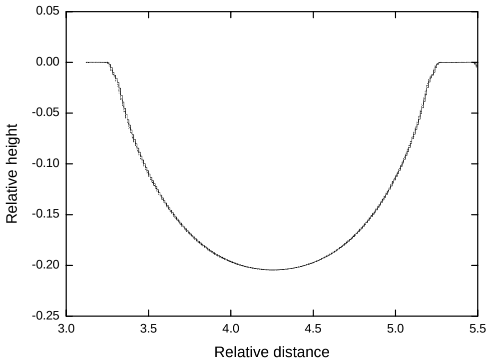

Figure 5. The comparison of lens profiles in the horizontal (solid), vertical (dashed) and 45° oblique (chain-dot) directions.

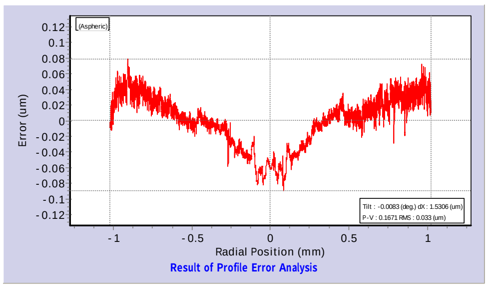

Figure 6. The difference of the profile between the optical design and the molded lens

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