An experimental study of the injection moulding of optical lenses

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Abstract

There are many parameters involved in an injection moulding process, and more importantly, an optical lens needs precisely controlled surface contours, determination of the processing conditions for lens moulding is very complicated. The objective of this work is to investigate experimentally some effects of the plastic product design and the moulding conditions on the replication of surface contours of lenses. A spherical plano convex lens was designed and moulded using cyclo olefin copolymer (TOPAS). The surface profiles of the lenses moulded under different processing conditions were measured using a laser interferometer. The residual stresses of the lenses was analysed using a polarimeter. The process parameters studied included holding pressure and mould temperature. A modulation Transfer Function (MTF) was used as method of describing lens performance. The study shows that in addition to the process parameters the product design also plays a vital role in the injection moulding of the lenses.

1. Experimental

The optical design of the lens was done using the Lensmaker's equation. The equation can be greatly simplified because the lens thickness d was very small compared to the surface radiuses. In this study there are basically four factors that determine the focal length of a lens and the well-known formula can be written as follows [1].

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

For the plano convex lens second radius is infinite ($r_2 = \infty$). According the equation for the focal length (f) of 120 mm and Topas 5013 material n=1,526 (880 nm) a radius (r_1) of 63,12 mm was calculated. The wavelength was selected according to the final application of the lens. In our previous studies, Euspen Stockholm 2012, the product design was a single lens consisting an edge gate (Figure 1.). In that study it was concluded that the shape of the lenses differed from the required spherical shape. It was also concluded that there was heterogeneity of the refractive index in the cross section of the lens [2]. In this study a new product design was made to avoid the deviations of the surface contours and also to avoid volumetric shrinkage. The designed product was simulated with a Moldflow Adviser to confirm even volumetric shrinkage and proper filling of the part.

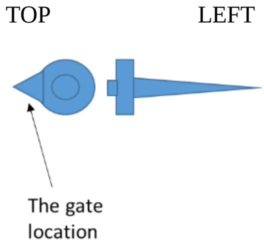

Figure 1. The single lens product design [2]

A mould base was designed to fix the diamond turned brass mould insert firmly with the help of a frame type bolster plate. The shape of an aperture of the bolster plate defined the outer geometry of the product. The mould base itself had delivery systems such as sprue, runner and gate. According to our previous studies, Euspen Stockholm 2012, the best quality lenses were moulded from COC Topas ®.[2]. For this reason Topas 5013 was used as moulding material in this study. The process parameters studied included injection speed, holding pressure and mould temperature.

2. Results and discussion

As a result from the product design and simulation study, the optimal results were found for the product which consists four lenses in a rectangular plate with the gating in the centre of the product (Figure 2). The final shape of the lens (Diameter 10 mm) is cut by a laser or a milling technique from product.

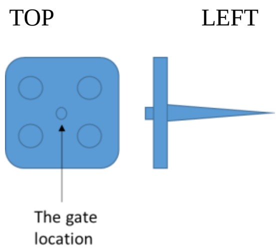

Figure 2. The optimised product design.

The surface profiles of the lenses moulded under different processing conditions were measured using a laser interferometer. The most critical moulding parameter for the precise replication of the surface contours was the holding pressure. The interferometry measurements showed 0,6 microns deviation from ideal spherical shape for the lenses manufactured using the optimised product design and moulding process. The image quality analysis was carried out by the modular transfer function (MTF) method [3]. A test object (100*15 mm), composed of bands of increasing spatial frequency, (2 to 200 line pairs per mm), was located at a distance of 10 meters from the lens. An image of test object was transferred to the object plane of the studied lens. A distortion of the image was analysed and processed using a special program developed by us using graphical programming package NI LabVIEW.

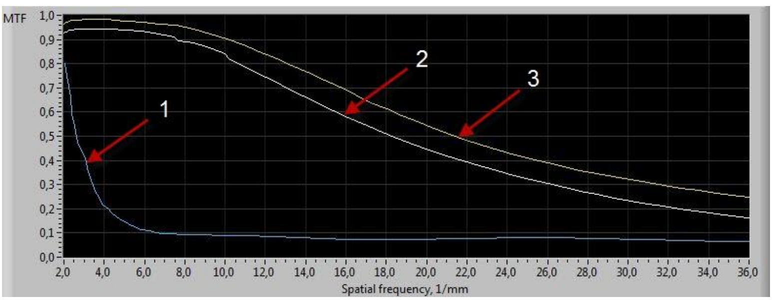

Figure 2. The MTF results of lenses (1- The single lens product design [2]; 2- The optimised product design lens; 3-the glass lens).

It can be clearly seen from the MTF curves (figure 2, curves 2 and 3) that the lenses moulded with the optimised product design are closely similar as the reference glass lens. A small difference in the performance can be explained by the quality of the surface of the lens. The surface of the plastic lens had a small diffraction due to the diamond turning process. The MTF performance of the single lens product design [2] was considerably worse (figure 2, curve 1). This is due to the residual stresses and the refractive index inhomogeneity of the lens. That can be also seen also in the figure 3. which shows the results from the polarimeter measurements.

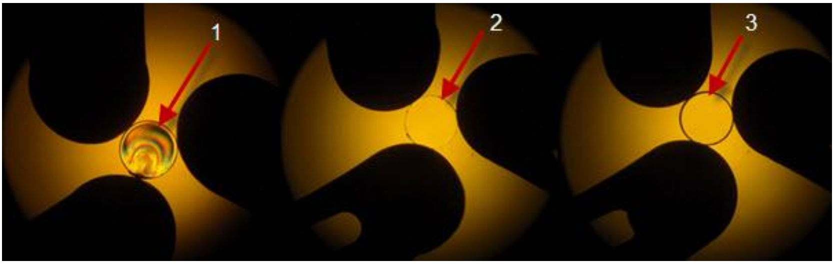

Figure 3**.** The residual stresses in optical lenses (1- The single lens product design [2]; 2- The optimised product design lens; 3-the glass lens).

3. Conclusion

Experimental results showed that the injection moulding process is capable for precision optics manufacturing. The study shows that in addition to the process parameters the product design also plays a vital role in the injection moulding of the lenses. The measurements confirmed the initial conclusion that the lenses produced by the new product design had significantly higher quality than the lens obtained in our previous work and are approaching the characteristics of a glass lens.

References

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