Local Injection Compression Molding for Resource Efficient Replication of Free Form Polymer Optics

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Abstract

This paper describes a manufacturing strategy for increasing resource efficiency in the production of polymer optics by use of a local injection compression molding process and a three-dimensional tactile metrology system. As this process offers a lot more parameters for the process optimization than a conventional injection molding process, a suitable evaluation method for the form accuracy and the influence of the form deviations on the optical function of the part is needed. The authors present a technique based on radial basis functions to make the deviations visible.

1 Introduction

Polymer optics for the use in LED lighting applications often have high wall thicknesses and complex wall thickness distributions. Therefore it is difficult to manufacture these polymer optics with high form accuracies by using a conventional injection molding process. The benefit of the use of a compression molding process for the whole part is often limited due to the differences in wall thickness and the consequent non-uniform cooling process. Local injection compression molding processes can be used for increasing the form accuracy. A polymer optics for LED street lighting has been selected as demonstrator for this paper. The optics has a maximum wall thickness of 10 mm and a wall thickness of 4 mm in its inner region.

2 Replication of Polymer Optics By Local Injection Compression Molding

The approach for the local injection compression molding process is illustrated in Fig. 1. The compression force is applied only on certain regions of the part that have no optical function so that there is no risk of negatively influencing the optical function of the part by causing scattered light or deviations in the distance between the optical surfaces. However, the use of the compression process allows for a considerable increase in form accuracy of the part and/or reduction of cycle time.

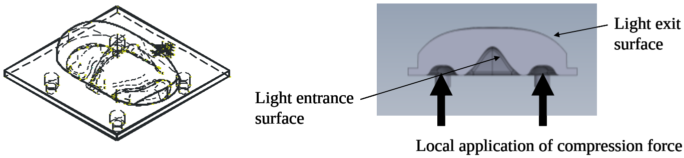

Figure 1: Polymer optics (left); local application of compression force (right)

The stamps for applying the compression force are connected with the ejector axis of the injection molding machine. By this means no additional hydraulics are needed and it is possible to use a fully electric machine for the replication of the optics. Due to the small size of the compression zone the forces for the local compression process are rather low. The mold allows for the variation of the compression gap between 0 and 2.0 mm. First results show that a significant increase in form accuracy can be achieved by use of the local injection compression molding process. Fig. 2 shows two optics that have been replicated with the different processes. The form deviations due to shrinkage that are clearly visible in the injection molded part could be eliminated by the use of the local compression process.

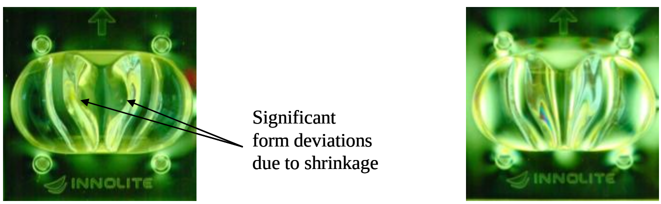

Figure 2: Optics manufactured with conventional injection molding process (left), optics manufactured with local injection compression molding process (right)

The approach also has significant potential to decrease cycle time for a given form accuracy. However, the use of the local injection compression molding process results in an increased number of parameters for the replication process, i.e. the compression gap, the compression force, and the starting time for the compression phase. These additional parameters yield a high potential for the optimization of the replication process but also make the process development a lot more complex. Therefore means for the precise characterization of complex polymer optics in a reasonable period of time are needed.

3 3D-Metrology for Freeform Optics

In order to gain a deviation map for a molded optics, metrology is used during and after the run-in of the process. Since the shape of polymer optics can be designed with more freedom, the optics in question has surfaces with angles of 80° and more. This makes it practically impossible to use interferometers or optical probes for a contour measurement. A downside of coordinate measurement machines for use with optical surface are the measuring times needed for a single measurement and the relatively low point density in combination with their individual measurement uncertainty.

A new development based on an adaptive surface reconstruction technique with radial basis functions (RBF) is capable of fitting low density, scattered data. Since RBF approximation does not force a fixed grid of centers, they are suited to model local effects on the discussed surfaces. Compactly supported radius functions, e. g. Wendland's function [1], can be used for mesh free surface approximation. The compact support radius of a radial basis function leads to a strictly positive definite and sparse linear system that must be solved to find the approximation to the measured data [2]. Depending on the number of centers, this calculation can be carried out on a standard computer in only a few seconds.

To find the number of points that are necessary to visualize the shrinkage in meaningful precision, points on the optical surface are placed with regard to the local photon flux through the surfaces. Therefore an approximation for the flux density is calculated from source ray data files that are available for LEDs and other light sources. This is used to place points on the surface following the local flux density and in order not to waste measurement time in surface areas that do not contribute to the illumination of the target area.

Experiments have been carried out using between a hundred and several thousand points on the surface. While more points allow for the calculation of smoother deviation maps, e.g. for shrinkage compensation [3], only a few points are needed to give a visual feedback on the quality of the lenses to the machine operator. For the aforementioned optics the number of points has been varied between 225 and 1800. It shows that the mean form deviation is comparable (c.f. Figure 3). Measurements with sufficient point densities for process optimisation take less than 15 minutes on a Zeiss O-Inspect coordinate measurement machine.

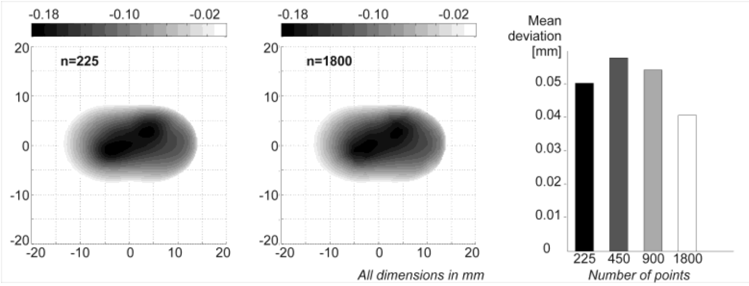

Figure 3: Form deviations measured with point densities of 1800 and 225 points respectively. Mean deviations for different numbers of points.

4 Conclusion

The setup of the mold and the development of the local injection compression molding process have shown that the approach has a very high potential for optimizing the form accuracy of the replicated polymer optics and for reducing the necessary cycle time. Using RBF for data display, only a minimum of points is necessary to acquire an accurate picture of the form deviations. This can be used to include coordinate measuring machines into the run-in cycles to find a resource efficient process with less iterations than before.

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References:

[1] Wendland, H., Scattered Data Approximation, Cambridge Monographs on Applied and Computational Mathematics, Cambridge University Press, 2004

[2] Wendland, H., Computational Aspects of Radial Basis Function Approximation, in: Topics in Multivariate Approximation and Interpolation, K. Jetterer et al., Elsevier B.V., 2006

[3] Brecher, C.; Buß, C.; Kolb, P.; Wenzel, C.: Corrective Machining of Freeform Molds for Mass Replication, Proceedings of the 11th euspen International Conference, Como, 2011