

# **Shrinkage Modeling of Injection Molded Precision Optics**

Jay Udayasankaran\*, Nelson E. Claytor, Donald M. Combs, Oscar M. Lechuga,  
John J. Mader, and Rajesh Mittal

Fresnel Technologies, Inc., 101 W. Morningside Drive, Fort Worth, TX

## **ABSTRACT:**

Our group fabricates precision optics via the injection molding process. Specifications for these optics typically have tolerances at the sub-micron level. To successfully fabricate such parts, it becomes critical to have a greater understanding and control of all the processes involved in molding of the optics.

Traditionally, the steps in making of the molded optics include fabrication of mold inserts by the diamond turning process; injection molding; measuring the molded optics with a profilometer; compensating the mold inserts for errors; and again molding the optics with these compensated inserts. Sometimes, this process is done iteratively till the tolerance specifications are met. Obviously, this process is time consuming and quite prone to errors and failures.

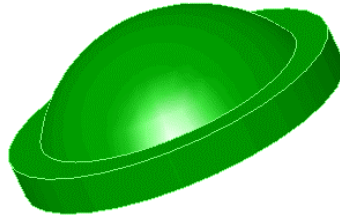
The primary objective of this work is to gain a better understanding of material shrinkage as one of the molding process errors and its effects on the form characteristics of the optics. A series of experiments will be performed with a set of plano-convex optics and the effect of shrinkage will be studied. Acrylic (PMMA), one of the popular optical materials, will be used for the study.

Shrinkage will be modeled with the data obtained from the above experiments. The effectiveness of the model thus developed will be evaluated, and the results will be discussed.

## **BACKGROUND AND MOTIVATION:**

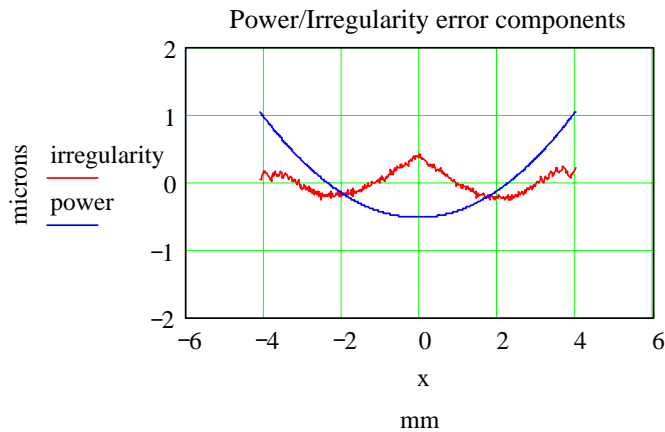
Traditional methods of manufacturing polymer optics include diamond turning, which although well controlled, is a time consuming and expensive approach. Mass production of optics via this process is not economical. Fabrication of precision optics via the injection molding process offers considerable benefits in terms of ability to mass-produce at a minimal cost. However, the injection molding process has its own constraints that need to be addressed, especially when tighter tolerances are specified.

In this project we will study the process of injection molding and the effects of material shrinkage on a plano-convex lens like the one shown in Figure 1. A plano-convex lens was chosen because it is simple to fabricate and evaluate, but detailed enough to provide valuable information about the process.



**Figure 1: Plano-convex test lens**

A brief description and background on how tolerances are generally specified is in order. In the past, when optical test surfaces such as flats and spheres were used to check the conformance, tolerances for radius of curvature of the lens were specified in terms of a “wave” or a “fringe”. Usually a wave refers to one wavelength from a standard source such as a red helium neon (HeNe) laser. The HeNe wavelength( $\lambda$ ) in air is 632.8nm. The most commonly used specification includes tolerances for two terms, namely power and irregularity. Power usually refers to an error component that can be approximated by a second order polynomial and any higher order component of the error is referred to as irregularity. An example of power and irregularity error is shown in Figure 2.



**Figure 2: An example of power and irregularity error components**

We usually get orders for injection molded plano-convex lenses with tolerance values, for power and irregularity in the range of 1-1.5 $\lambda$ . Our experience indicates a better understanding of the material shrinkage is needed in order to mold a part within this tolerance value. The objective of this study is to gain a better understanding of the material shrinkage and create a shrinkage model based upon a set of experimental data. We expect that this model will help us predict in advance what the shape of our mold inserts should be, in order for us to fabricate in-tolerance parts in as few steps as possible.

## EXPERIMENTAL APPROACH:

Three variations of the plano-convex lens shown in Figure 1 will be fabricated. The convex side is spherical in shape. The radius of the curve, and thus the sag, will be varied in each part. All other dimensions remain constant. The dimensions of the three parts that are being fabricated are shown in Figure 3.

In our past experience we relied on a nominal value from the material manufacturer for the shrinkage compensation. However, we would like to experimentally determine the value, and we would also like to determine if there is any relationship between the volume of the part and the amount it shrinks.

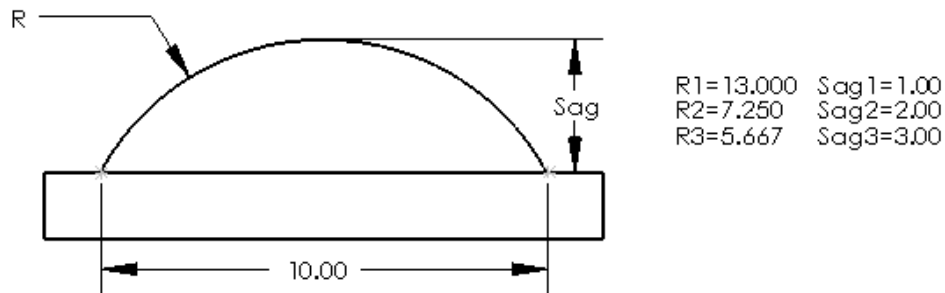


Figure 3: Dimensions of the fabricated parts in mm

The first set of experiments involved fabricating three mold inserts to the design dimension, without including any shrinkage value. The injection molding process was optimized to obtain the best possible part, and the process will be maintained constant except for the injected volume for all the parts.

We expect that measurement of the molded parts should yield us the following.

1. Shrinkage value for each part.
2. Relationship between the volume of the part and its shrinkage, if any.

Equipped with this information, we will re-fabricate the respective mold inserts with appropriate shrink factors that were determined empirically in the above steps. This simple-geometry lens is particularly suited for linear-model approximation (linear change of dimensions and radii resulting primarily in “power” error component). More complex lenses, for example a lens with drastically changing thickness or high aspect ratio, may exhibit non-linear shrinkage resulting in severe “irregularity” error component, which is not trivial to model but still can be compensated. We will again re-measure the molded parts and determine whether we were able to mold parts within the tolerance of  $1-1.5\lambda$ .

## RESULTS AND DISCUSSIONS:

Our primary aim was to achieve the power and irregularity tolerance on convex side of the lens. Hence, our results and discussions will concentrate on the measurements made on the convex side of the lens. In our experience we have noticed that tolerances on dimensions like center thickness, outside diameter, flange thickness etc. are quite lenient and it is relatively simple to achieve these tolerance specifications.

In the first iteration, the mold inserts were fabricated as discussed in the earlier section and the molded parts were measured using a profilometer. The measurement result for one of the lenses is shown in Figure 4. This figure shows the residual error from a least squares fit of the data to a radius, which was allowed to vary. Table 1 shows the radius value for all the three parts. Three samples were measured for each part and the “Part Radius” column in Table 1 contains the average value of the measurements.

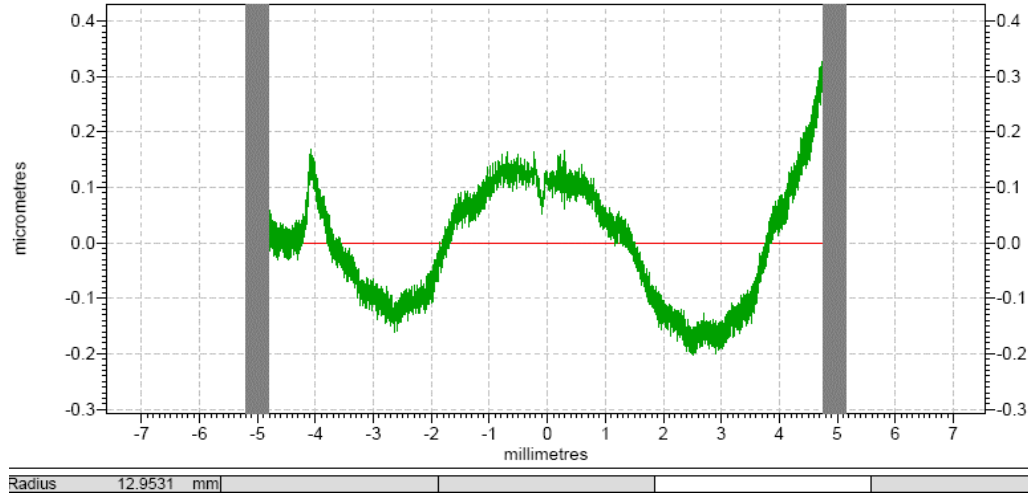


Figure 4: Radius of the 1mm molded part

Part with sag of	Insert Radius(mm)	Part Radius(mm)	Shrinkage %
1mm	13.000	12.954	0.35
2mm	7.250	7.210	0.55
3mm	5.667	5.633	0.61

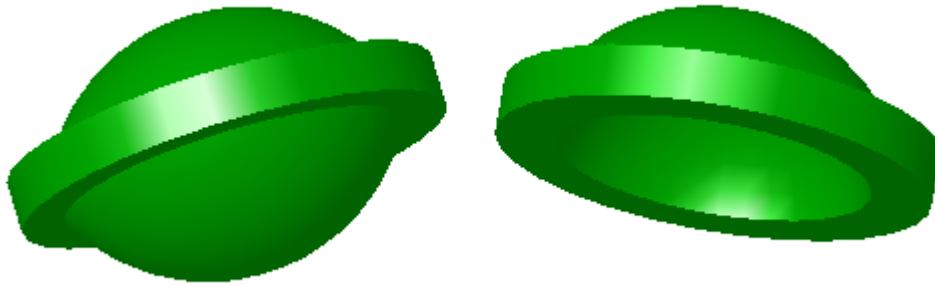
Table 1: Measurement results

The results clearly indicate a relationship between volume of the part and the amount it shrinks. The higher the volume of the part, the greater is the shrink percentage. This step clearly helped us to determine the actual shrinkage of the part. The number supplied by the manufacturer is good enough for many applications, but cannot be relied on for fabricating precision optics. We will fabricate three more mold inserts with these empirically determined shrinkage values. Also we will verify the results by fabricating another plano-convex lens. This time the convex side will be aspheric instead of a sphere

like in our test cases. We expect to fabricate this lens in-tolerance at the first iteration itself. The results will be presented in the conference.

### **CONCLUSION AND FUTURE WORK:**

This project was phase 1 of a detailed study we plan to perform at Fresnel Technologies, Inc. We intend to expand this study to include more complicated optics. Some of the examples are as shown in Figure 5. Our experience indicates that a plano-convex optic behaves differently than a biconvex optic, or particularly a meniscus optic. Also we would like to perform research upon how various parameters in injection molding has an effect on the molded part.



**Figure 5: Example of optics that will be evaluated in the future**

\*corresponding author: [jay@fresneltech.com](mailto:jay@fresneltech.com), +1 817 926 7474 Ext-129