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Modification of an Injection molding machine to mold micro parts with a LIGA mold

Emil John Geiger

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Louisiana State University
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Abstract

In this project, an injection molding machine was modified to accept LIGA micro molds. Of significance, the modification incorporated ejector pins to automatically eject molded LIGA parts after injection. A LIGA mold tool with tapered sidewalls was inserted into the modified injection molding machine and experiments were performed. The LIGA mold with tapered walls (which allows easier ejection of the molded parts), combined with the modifications to the injection molding machine, made it possible to greatly reduce cycle time to approximately three minutes and virtually eliminate warping of the parts.

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Introduction

The three-step LIGA process has long been touted as a viable micro machining process to economically mass produce ceramic, metal, or polymer high aspect ratio micro structures (HARMs). LIGA uses x-ray lithography to etch a well-defined pattern within a sheet of x-ray sensitive resist. Then an electroforming step is used to fill with metal the voids within the patterned resist sheet. The electroforming step results in a metal mold which consists of a flat plate covered with metal micro features. Finally, the mold is used to mass-produce polymer, ceramic, or metal parts via injection molding or embossing. An example of a molding tool is shown in Figure 1a and the resulting polymer molded part is shown in Figure 1b.

Figure 1a: LIGA molding tool

Figure 1b: Polymer part from LIGA mold

Over the last five years, both injection molding and hot embossing have been used to fabricate parts using LIGA molds. Due to its simplicity, hot embossing was the primary method to fabricate parts. Hot embossing involves placing a polymer sheet within a press. Both surfaces of the press are heated, and the mold tool is mounted to the upper surface. When the press is closed, an imprint of the mold pattern is created within the polymer. After the press is opened, the part is removed. The current embossing setup

is illustrated in figures 2a and 2b. To prevent air from getting trapped between the mold insert and the polymer sheet (which destroys feature definition) a vacuum is usually drawn prior to embossing. However there are three main disadvantages to the embossing process. First, the cycle time for the embossing time is 20-30 minutes mostly due to the heating and cooling of the vacuum. Second, the parts are typically warped due to forces associated with extracting the part from the mold and the temperature difference between the top and bottom surfaces. Significant effort and time is wasted flattening the parts after embossing. The last disadvantage is the extensive labor involved with preparing the plastic part before embossing, having to manually place and remove the part for every cycle, and having to flatten the warped parts after embossing.

Figure 2a: Hot-embossing machine

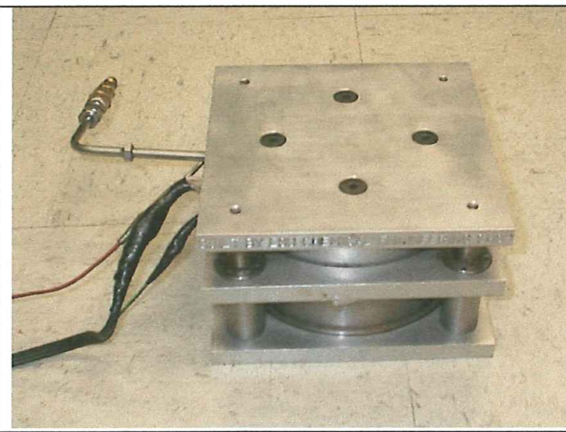

Figure 2b: Vacuum Chamber for hot-embossing

The alternative to embossing is injection molding. Injection molding is accomplished by melting a polymer, then injecting it at high pressure into a mold cavity containing the mold. After injection, the part cools, solidifies, and is extracted. The theoretical cycle time to injection mold micro features, which is again dominated by the period of time required to heat and cool the mold tool, is approximately three minutes – a

great improvement over embossing. However, the actual cycle time to injection mold parts prior to this effort was much longer.

With the previous design, the LIGA mold insert was mounted on the movable side of the cavity (the side that moves when the mold is opened), and a retaining ring was placed on the stationary side. This design is shown in figure 3. After injection, the mold tool was pulled back and separated from the molded part which remained bonded to the stationary side of the mold cavity. To separate the molded part, the stationary side of the cavity had to be completely removed from the injection molding machine, the retaining ring had to be removed, and finally the part could be taken out of the mold.

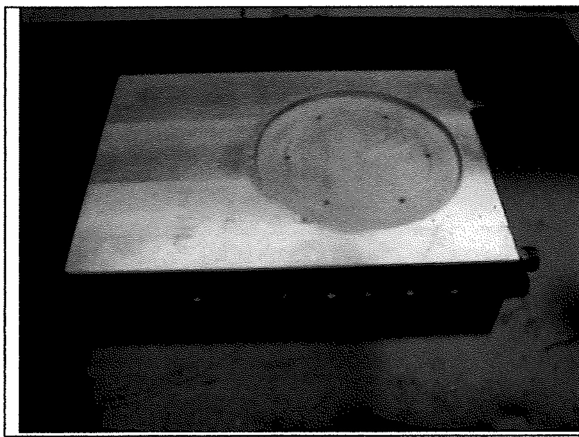

Figure 3a: Movable side from old design

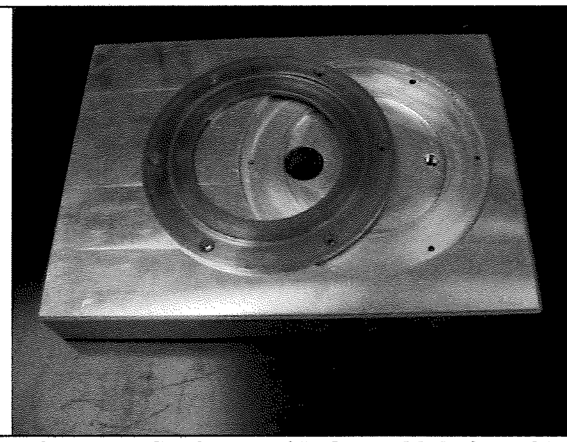

Figure 3b: Stationary side from old design with retaining ring

Figure 3c: Molded part from old design.

This setup had several limitations. First, it was extremely labor extensive. While the mold does slide out of the machine fairly easily, the mold is hot, heavy, and difficult to lift into and out of position. The second problem with this design is that while the operator is manually taking the part out of the mold, the molten plastic in barrel of the injection molding machine is "cooking." This "cooking" of the molten plastic would change the flow properties of each injection making it difficult to obtain consistent results. These two problems made the previous design impractical to the point where hot embossing was still the preferred method of molding.

The purpose of this project was to modify the existing injection molding platens (the stationary and moving plates that form the mold cavity and contain the mold tool) to eliminate the existing disadvantages and therefore make injection molding the obvious choice for molding.

Design and Fabrication

The primary feature that distinguishes the new design from the old design is the use of ejector pins. Other noticeable features that will be discussed include the sprue puller, vacuum system, interchangeable mold inserts, and the heating and cooling system. A Pro/Engineer model of the design is provided in figure 4a and 4b. On movable side (figure 4a), there is a cavity where the metal LIGA mold sits, the sprue puller, and the channels for the heaters and cooling water. The stationary side of the injection mold tool (figure 4b) has a tapered sprue bushing (passage between the barrel of the injection molder and the mold), a circular cavity with tapered sides that defines the overall dimensions of the part, a runner to connect the cavity to the sprue, and the vacuum system.

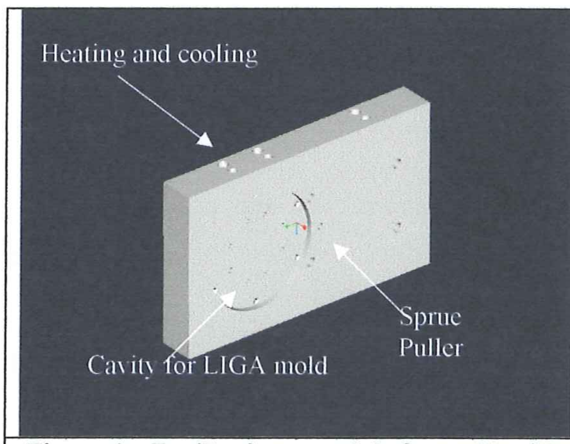

Figure 4a: Pro/Engineer model of movable side

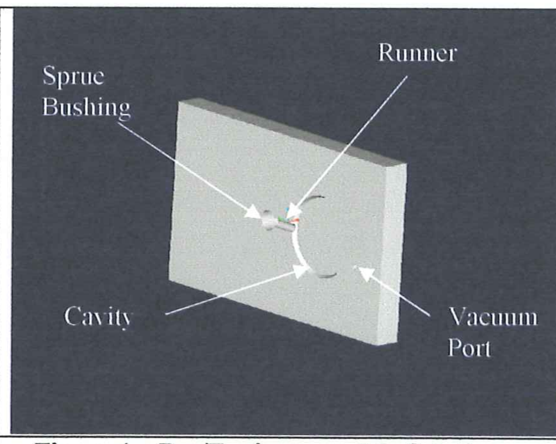

Figure 4a: Pro/Engineer model of stationary side

The new injection mold tool is designed to work as follows:

1. The cartridge heaters heat the LIGA mold insert to the temperature prescribed by the operator.
2. The mold closes and the plastic is injected.

3. After the injection is complete the operator turns on the water to cool the mold.
4. The mold opens and the part sticks to the movable side due to the sprue puller and the friction of the LIGA mold insert.
5. The ejector pins push forward, demold the final plastic part from the LIGA mold insert, and push the sprue out of the sprue puller. The part then falls into a bin below.
6. The cycle is repeated.

Ejector pins are commonly used in industry and were incorporated into this design by drilling holes in the metal LIGA mold insert. There are eight ejector pins located in a roughly circular pattern around the LIGA features with one additional pin in the center of the pattern as shown in figure 5. The pins were located to allow the largest possible LIGA patterns that were within the capacity of the machine. The mold was designed such that if any of the pins were not needed or if they would interfere with the function of the LIGA part, they could be removed as long as enough pins remain to eject the part.

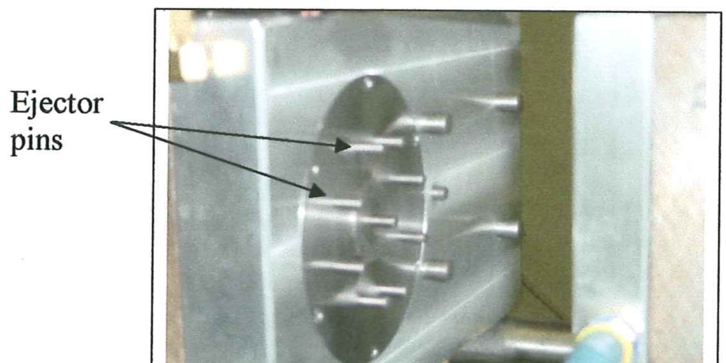

Figure 5: Extended Ejector pins

Sprue pullers, also used in industry, are used to pull out the sprue (plug of plastic in the sprue bushing) so that it is clear for the next cycle. It is a small hole opposite the sprue bushing with a reverse taper. At the bottom of the hole there is an ejector pin that pushes the sprue out with the rest of the part. The sprue puller also gives the small frozen

plug at the beginning of the shot a place to go so that it does not interfere with the LIGA part. Figure 6 shows the sprue puller.

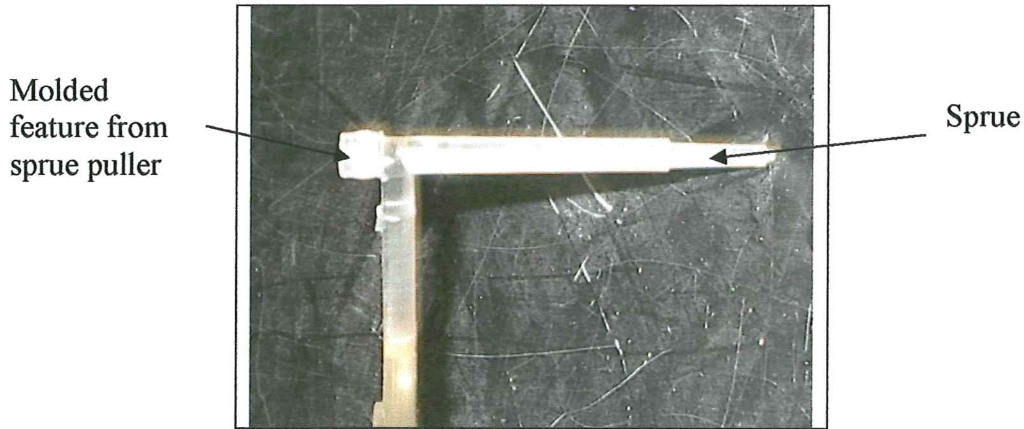

Figure 6: Sprue puller and sprue

Injection mold tools are typically vented by the use of shallow channels, on the order of a couple of thousandths of an inch, which are situated on the parting line and lead from the mold cavity to the edge of the mold. In this type of setup the plastic melt pushes the air out of the mold as it is injected. The vacuum system in this design borrows from this idea by using a vent that leads to a vacuum line as shown in figure 7. Vacuum grease was applied to the mating surfaces of the mold to improve the quality of the vacuum. While a perfect vacuum is practically impossible to create due the presence of the ejector pins, the vacuum system was capable of pulling a vacuum on the order of 25 inHg.

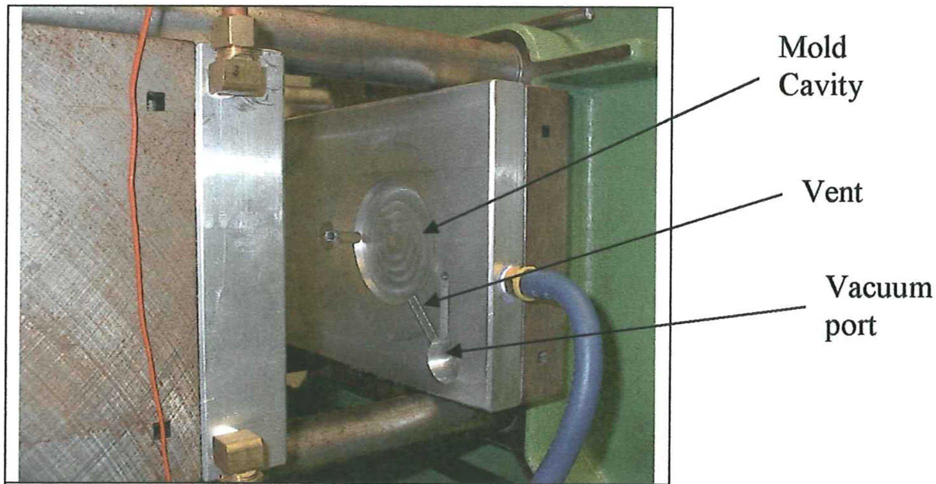

Figure 7: Vacuum System

The mold was designed so that the LIGA mold inserts could be interchanged without modifying the mold. This is accomplished by standardizing the metal plates on which the LIGA structures are electroplated and the positions of the ejector pins. This is demonstrated in figure 8.

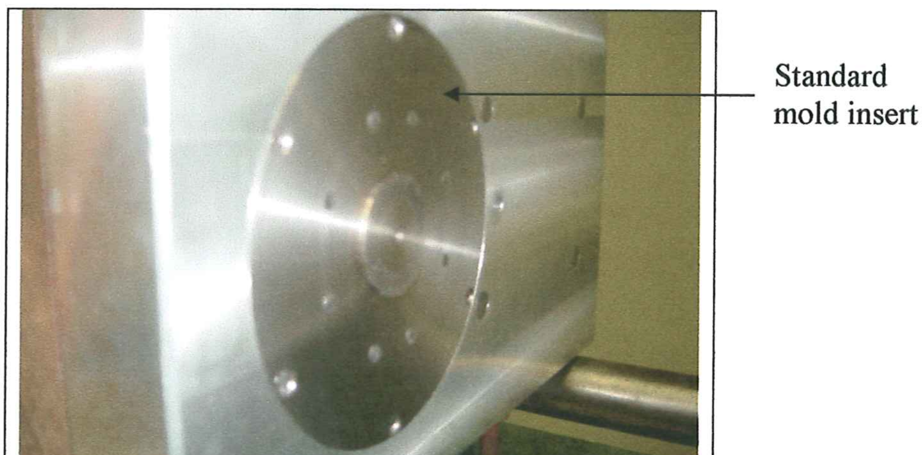

Figure 8: Interchangeable mold inserts

The last feature which should be noted are the heating and cooling channels shown in figure 9. Three cartridge heaters heat the LIGA mold so that the plastic melt does not prematurely freeze upon injection. [1] After injection, water flows through the three cooling channels, located directly behind the heaters, to cool the part until it is rigid enough to demold without warping.

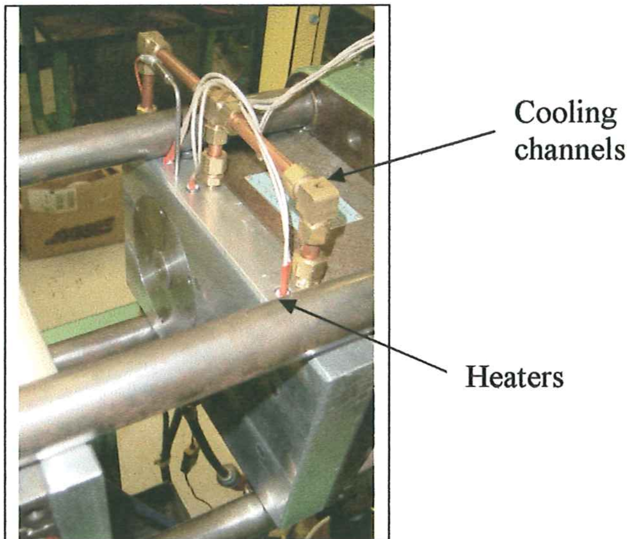

Figure 9: Heater and cooling channels

The mold tool was designed in Pro/Engineer and CNC machined out of aluminum. Aluminum was chosen because its high thermal conductivity helps minimize the cycle time.

Molding Experiments: Description and Results

The new injection molding tool was implemented successfully and was used to evaluate the effectiveness of adding a taper to LIGA molds. In the past, LIGA molds have been limited to vertical sidewalls. Now, however, it has been demonstrated at LSU that LIGA features can be made with a taper to facilitate easier demolding. [2] This injection molding tool was used to prove this concept by comparing the results of molding a LIGA mold insert with taper to a LIGA mold without taper.

Using the modified injection molding machine and a LIGA mold with tapered features, LIGA parts were injection molded with a cycle time of approximately three minutes and the resulting parts were flat upon ejection. The advantage of the taper was proven as a similar LIGA insert with vertical sidewalls could not be successfully molded without the microstructures breaking upon ejection. The micro molded LIGA structures are shown in Figure 10.

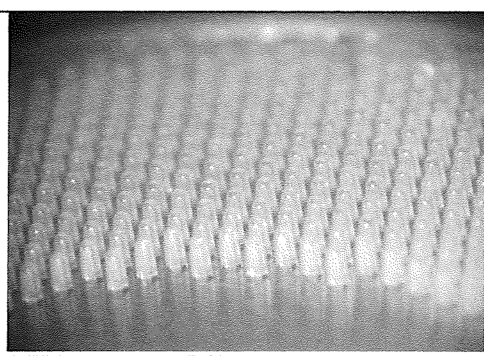

Figure 10a: Molded LIGA microstructures

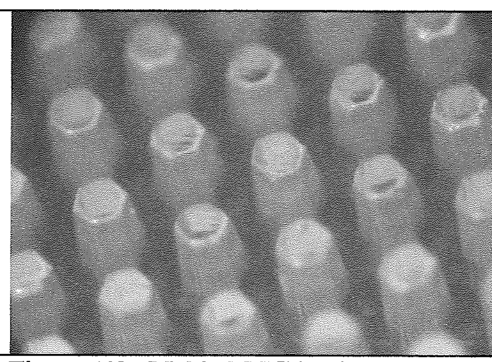

Figure 10b: Molded LIGA microstructures

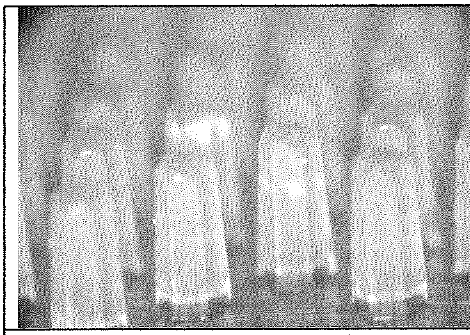

Figure 10c: Molded LIGA microstructures

Conclusion

In this project the existing injection molding setup was modified to make it far superior method of molding when compared to hot-embossing. These advantages are summarized below:

- The total cycle time is about 3 minutes, whereas the embossing requires a minimum of 20 minutes for similar geometry.
- The preparation to begin molding, which consists of dumping plastic pellets into the hopper, is minimal in comparison to embossing
- The operator controls the entire process from the control panel. Physical labor is reduced and the process is much safer.
- The parts are automatically ejected from the mold rather than having to be removed by hand.
- The parts are flat upon ejection eliminating the need for any post-processing to flatten warped parts.

Acknowledgements

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References

[1] M. S. Despa, K. W. Kelly, J. R. Collier, "Injection molding of polymeric LIGA HARMs", *Microsystem Technologies,* Volume 6, Number 2, December, 1999, pages 60-66

[2] Ryan Turner, "Tapered LIGA mold insert", Thesis for M. S. in Mechanical Engineering, Louisiana State University, submitted December 2002.