Indirect Metal Composite Part Manufacture Using the SLS Process

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ABSTRACT

As a near term alternative process to direct metal sintering, an intermediate polymer binder is combined with powder to produce green preforms with the Selective Laser Sintering (SLS) process. To produce parts with desirable strength and dimensional control, the binder is gradually removed from the green preform (obtained from the SLS process), and the remaining form is lightly bonded. This porous part is then infiltrated. Final part density, shrinkage, and strength data are presented. An injection mold insert was fabricated from this material and used to mold ABS, PMMA, polyester, and polycarbonate parts. To date, the mold insert has survived 176 shots at injection pressures up to 35,000 psi and melt temperatures of up to 300°C.

INTRODUCTION

Molds to be used for the injection molding of thermoplastics are traditionally manufactured from cast metal by precision metal cutting devices. The machining and polishing times are quite extensive and the costs are correspondingly high. These high costs and production times effectively preclude the preparation of prototype plastic parts by injection molding. Prototype plastic parts are consequently usually manufactured by other processes. Unfortunately, the properties of such parts may not be truly representative of those of injection molded parts due to the thermal stresses and molecular orientation inherent to the injection molding process.

Clearly, there is a great need for low cost, low production time molds which could produce the 50 - 500 plastic parts needed to prove a design. The University of Texas at Austin is presently investigating new material systems and processes that potentially permit the rapid fabrication of molds by SLS and subsequent processes. In addition to cost and time savings, potential advantages to mold making by the SLS process include: incorporation of custom cooling channels and other features that are not easily machined, ease of manufacturing duplicate molds, opportunity to evaluate the runner system prior to machining a production mold, and ease of cavity design by use of commercial CAD solid modelers.

Two of the important goals of the material system and process include: minimal, predictable, shrinkage from original CAD design, and sufficient strength for withstanding injection pressures and temperatures. With most powder processes, there is usually a trade-off between minimal shrinkage and strength. In an attempt to minimize shrinkage issues and still have enough strength, a powder/infiltrant system was chosen as the first material system for investigation.

DISCUSSION

The target process for manufacturing molds in the SLS process is outlined in figure 1:

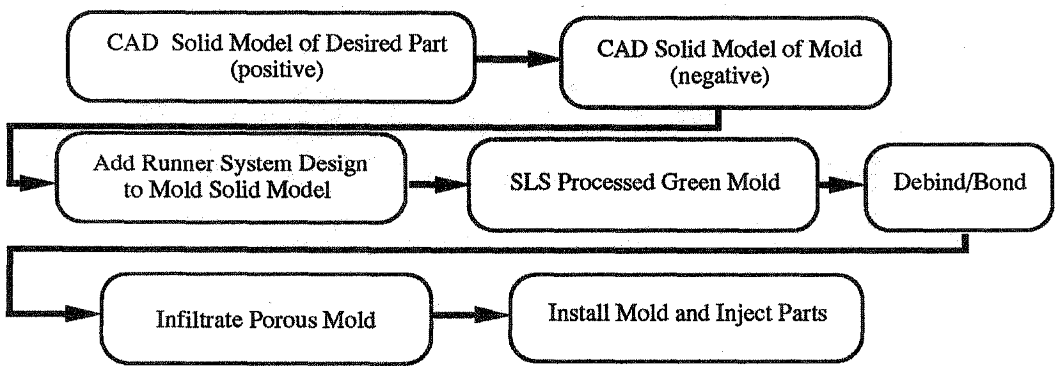

Figure 1. Process for fabricating molds

In an effort to arrive at this process, the material system and bonding cycle performance needed to be evaluated. To determine preferred bonding cycle and material system, green three point bend bars and 1 1/4" thick blocks were fabricated with different powders. Different bonding cycles were evaluated to determine shrinkage and strength of the fired bars prior to infiltration. Strength measurements were also taken on three point bend bars that were infiltrated with a total of four different infiltrant systems.

An initial preferred powder/infiltrant system was selected. Prior to fabrication of the mold insert using the SLS process, a mold insert was fabricated with the process outlined in figure 2. The insert was fabricated in this manner because the selective laser sintering equipment available at the university is not capable of manufacturing parts of the required scale. However, strength tests on bars made both in the SLS process and in the oven show the resultant material systems to be effectively the same.

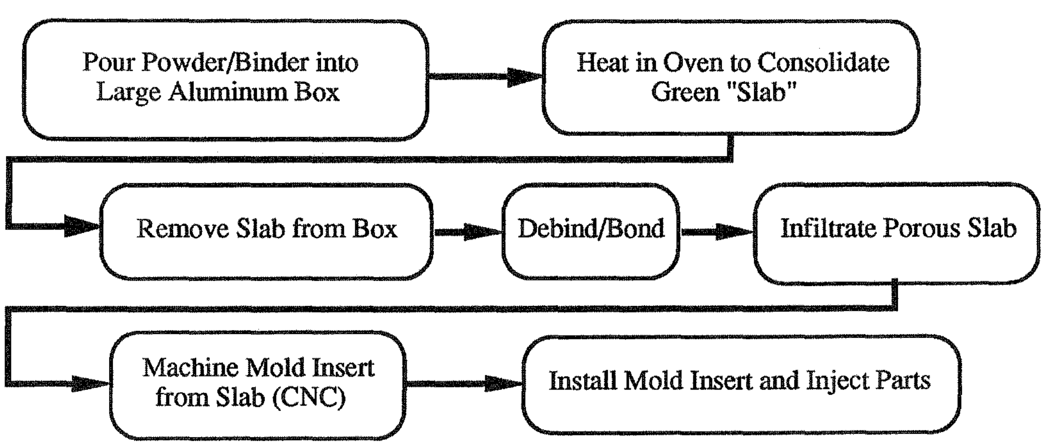

Figure 2. Process for fabricating molds for material evaluation

Figure 3 shows a photograph of a completed mold assembly. For testing purposes, a standard Master Unit Die plaque mold was modified by replacing the steel plaque cavity with the insert. As shown in the foreground, the insert is 8.4" x 5.3" x 0.6" and the part cavity is 5" x 2.5" x 0.25". It is equipped with seven standard ejector pins (4 through holes in the part cavity, and 3 through holes in the runner cavity). The runner is 1/4" in diameter and the letters are 1/16" deep. The insert was not channeled for water cooling. For this reason, the cooling times were kept long (near 55 seconds).

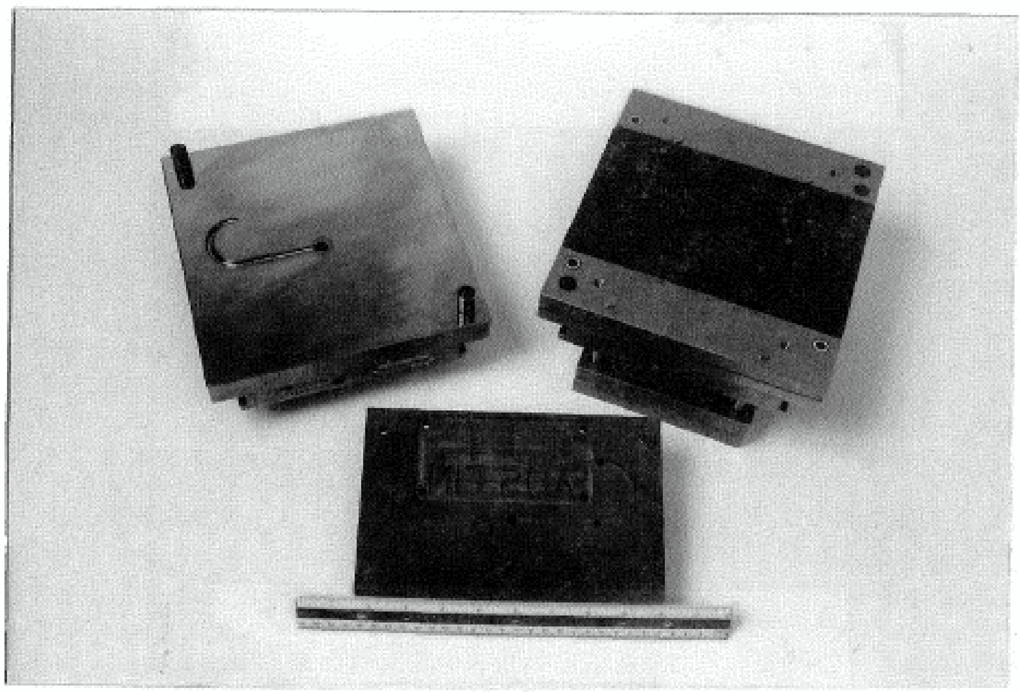

Figure 3. Mold Assembly

RESULTS

Table 1 shows the average density and strength measurements taken on 10 SLS processed three point bend bars with the same material used to fabricate the tooling insert.

TABLE 1
SLS Processed Three Point Bend Bar Data

	Relative Density (%)	Modulus of Rupture (psi)
Green:	51	421
Porous :	32	95
Infiltrated:	98	3,841

These same bars demonstrated linear shrinkages of 0.45% in the X direction, 0.82% in the Y direction, and 1.41% in the Z direction. To date, the 1 1/4" thick blocks have also shown linear shrinkages of less than 2% in all directions after bonding.

Table 2 shows the molding conditions used to inject the first 176 shots into the mold insert.

TABLE 2
Molding Conditions

Polymer	# of Shots	Peak Inj. Press. (psi)	Temperature (°C) zones 1, 2, 3, & 4	Injection Time (sec)
ABS	101	8000	200, 190, 200, 200	3
PMMA	28	35000	175, 170, 160, 160	3
Kodar A150	22	35000	275, 275, 275, 275	4
PC	25	35000	245, 275, 300, 300	4

Additionally, for all plastics, the injection hold pressure time was set to 2 seconds and the cooling time was set to 55 seconds.

Observations of the molded parts show only 2 defects during the 176 shot run. Both of these defects occurred while molding PMMA. At shot 105 a hairline fracture (perhaps surface) started at one of the ejector pins and grew over the next 25 shots to a total length of approximately one inch. The crack did not noticeably propagate further after that point and did not affect the performance of the mold other than the faint mark left in the moldings. At shot 123, a small but noticeable chip of material around another ejector pin broke loose. This breakage progressed through shot 127 to a total size of approximately 1/16" x 3/16" x 1/16". This defect, similar to the hairline fracture, did not grow further. We are currently in the process of evaluating mold erosion by measuring dimensions of the molded parts.

CONCLUSIONS

The generally low shrinkages associated with post processing green shapes suggest acceptably good geometric fidelity for successful molding of plastic parts. Our evaluation of the mold material is presently incomplete, however, these initial results are most encouraging. They suggest that even materials with relatively low strengths can be adequate for prototype insert service, provided reasonable care is exercised in the overall tool design. Mold erosion does not qualitatively appear to be significant. The deficiencies seen near 2 out of 7 ejector pins are of some concern. We are presently developing a higher strength material that could correct this problem. Ejector pin sleeves could also be installed in future designs.

We intend to prepare new inserts with cooling channels and various geometric features to gain additional understanding of the relationships between insert material properties, mold design, and molding conditions.

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