# RapidSteel Part Accuracy

Brent Stucker, Muni Malhotra, Xiuzhi Qu, Peter Hardro, Natalie Mohanty, Rapid Manufacturing Center, Dept. of Ind. & Mfg. Engr., Univ. of RI, Kingston, RI 02881. (401-874-5187, stucker@uri.edu, www.egr.uri.edu/ime/RMC)

## INTRODUCTION

In order to assess the effect of various furnace processing parameters on RapidSteel part accuracy, a series of experiments were performed on linear dimensional changes during processing of RapidSteel 2.0 and LaserForm ST-100. An understanding of these dimensional changes is critical for building parts and tools which are capable of being used in high tolerance applications and for finish machining of near-net shapes to high tolerances.

A unique part was designed for this study and is shown as Figure 1. This part has both internal and external measurable dimensions in the x, y and z axes. The smallest dimension in each direction is 0.3 inches and the largest dimension is 3.0 inches. This provides an order of magnitude difference between the smallest and largest dimensions.

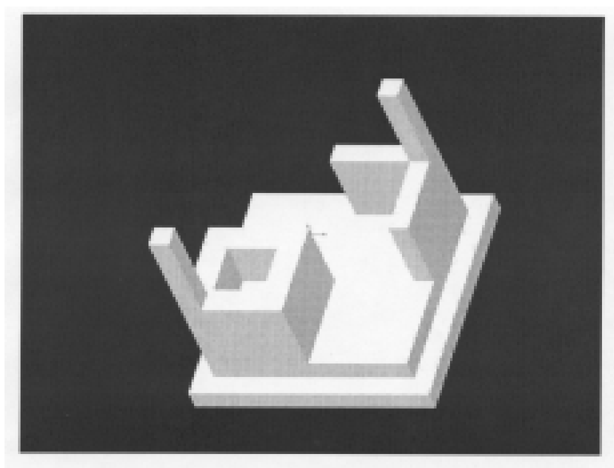

Figure 1. Benchmark Geometry

RapidSteel 2.0 (RS2) is a commercially available metal material from DTM Corporation. It is made by Selective Laser Sintering of stainless steel 316 powders with polymer binders followed by a binder burnout and sintering furnace run, and a second infiltration furnace run where a 90% Cu, 10% Sn bronze is infiltrated into the porous stainless steel structure.

LaserForm ST-100 (ST-100) is the latest version of RapidSteel and is a stainless steel 420 material that is sintered and infiltrated in one furnace run. The significant difference between RS2 and ST-100 is that the ST-100 has a broader particle size range, with fine particles not being screened out. These fine particles allow the ST-100 material to be sintered at a lower temperature than the RS2 powder, which makes possible the single furnace run for sintering and infiltration. Benefits of ST-100 include that it is a magnetic material and can be fixtured using magnetic chucks and that the finer particles allow for greater feature definition, sharpness of corners and strength of green parts.

## EXPERIMENTS

A study of RapidSteel 2.0 was carried out by Muni Malhotra as part of his Master's Thesis at the University of Rhode Island entitled, "Dimensional Variation Analysis of Rapid Prototyping Materials." Three factors were chosen for this design of experiment, with two replicates of each factor. These factors and their levels are:

| | |
|---|---|
| Pressure: | 10 Torr and 800 Torr |
| Infiltrant Amount: | 80%, 95% and 110% by volume of brown part |
| Ramp Rate: | 2 °C/min and 4 °C/min |

The infiltrant percentage was based on 100% being the theoretical amount of infiltrant needed to fully fill the porosity. This was calculated based on the weight and volume of the part after sintering compared to the density of stainless steel 316.

Measurement of 24 dimensions on each part (approximately 4500 measurements in all) were recorded and analyzed. These measurements were taken after the SLS process and after each furnace process. All dimensional measurements after the furnace processing could be compared to the post-SLS state, rather than the .STL file, to eliminate effects of variation from SLS processing. Although all of the dimensional data was obtained for each part, only a fraction of it has been analyzed to date.

A follow-up study on LaserForm ST-100 was performed. For this study, a slightly different combination of factors and levels was chosen. Two factors, ramp rate and infiltrant amount, were selected for this experiment. The levels for the factors are:

| | |
|---|---|
| Ramp rate: | 1°C/min, 2°C/min and 4°C/min |
| Infiltrant amount: | 70%, 80% and 90% by volume of green part. |

To date, the 1°C/min ramp rate for ST-100 has not been completed, although the other factors have been investigated for 2°C/min and 4°C/min.

## RESULTS

Three large dimensions (x3, y3 and z3) were used as the basis for the following analysis. Thus, all of the conclusions are statistically relevant just for 3.0" dimensions on RS2 and ST-100. Based on initial data analysis, however, it appear that these trends hold for other dimensions as well.

For RapidSteel 2.0, after using ANOVA tables to analyze the measured data we found that pressure has a significant influence on shrinkage for the first furnace run. Figure 2 shows the absolute dimensional change through the first furnace cycle. It can be clearly seen that increasing pressure reduces the shrinkage, while changes in ramp rate have no significant effect.

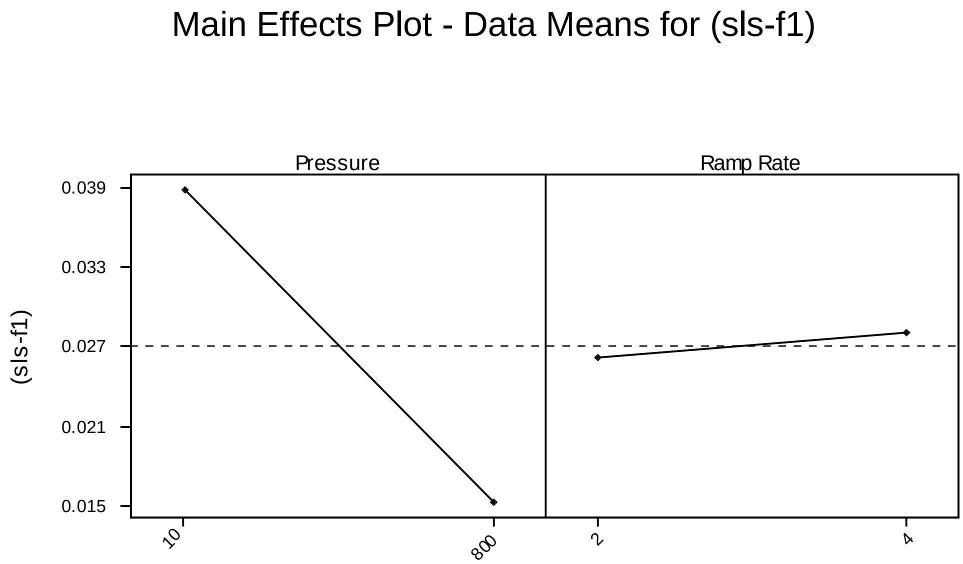


Figure 2. Changes in the x-direction for the first RS2 furnace run.

A main effects plot for the second RS2 furnace run is shown as Figure 3. This clearly shows that pressure has no significant effect on shrinkage for the second furnace run but that infiltrant amount does have a significant effect. The effect of ramp rate on shrinkage is statistically insignificant.

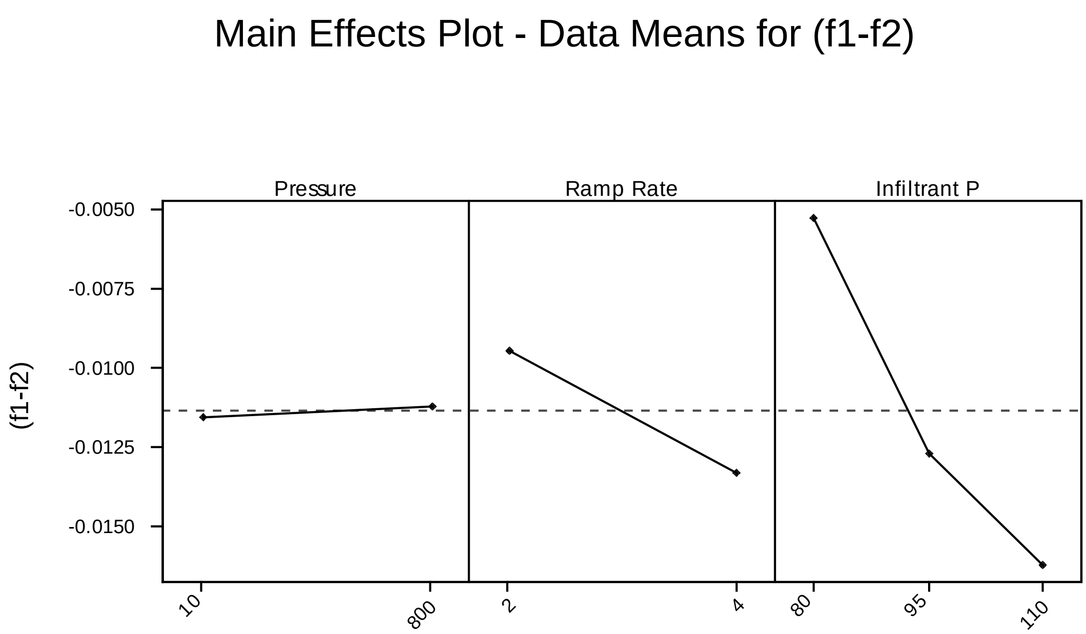


Figure 3. Changes in the x-direction for the second RS2 furnace run.

For accuracy purposes, the variation in shrinkage from different factors is more important than absolute shrinkage.  In addition, interaction from factors may be significantly more important the effect of a single factor.  Figure 4 shows the variance in shrinkage for the x-direction for different significant factor interactions for the second RS2 furnace run.  (There were no significant variance differences between factor combinations for the first furnace run.)

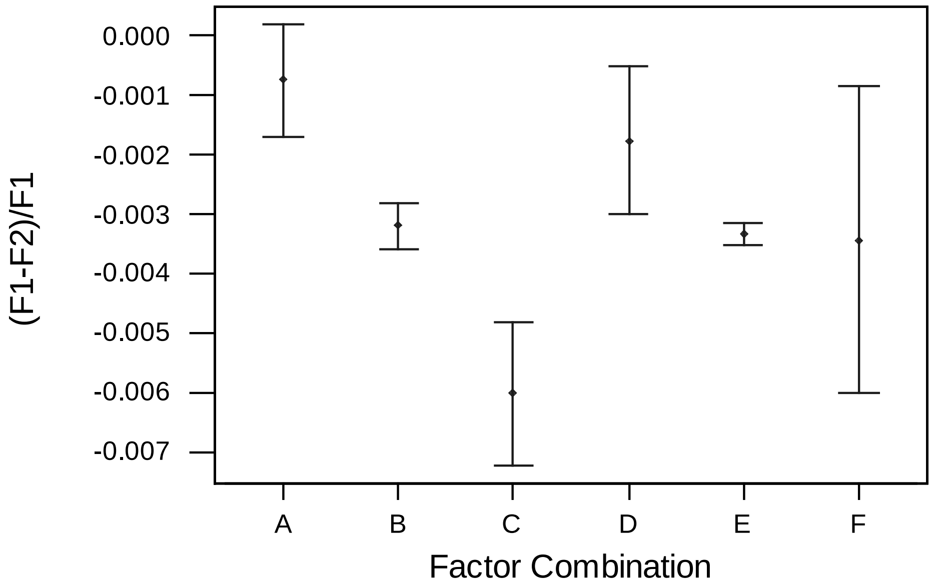


Figure 4.  95% confidence interval for variation in shrinkage for second RS2 furnace run.

The factor combinations in Figure 4 are:  A – 10 torr, 80%; B – 10 torr, 95%; C – 10 torr, 110%; D – 800 torr, 80%; E – 800 torr, 95%; and F – 800 torr, 110%.  This includes data for both ramp rates since ramp rate was not a significant factor, nor was its interaction.  It can be seen from Figure 4 that the lowest statistically significant variances are for factor combinations B and E, with 10 torr, 95% infiltrant amount and 800 torr, 95% infiltrant amount respectively.  Thus, it is recommended that a 95% infiltrant amount be used and the most economical pressure be used based on the furnace available to practitioners.

Figure 5 shows the overall percent shrinkage at 800 torr, 80% infiltrant amount and 4°C/min for the x, y and z dimensions for RapidSteel 2.0.  These particular ones are shown since they match one of the factor and level combinations used in the ST-100 study.  It can be seen from these graphs that the x and y shrinkage levels are comparable, but that the z direction has significantly more shrinkage than the x and y dimensions.  These graphs also show a larger variation in shrinkage for the small dimensions than for the medium and large dimensions.  This is due to measurement error.

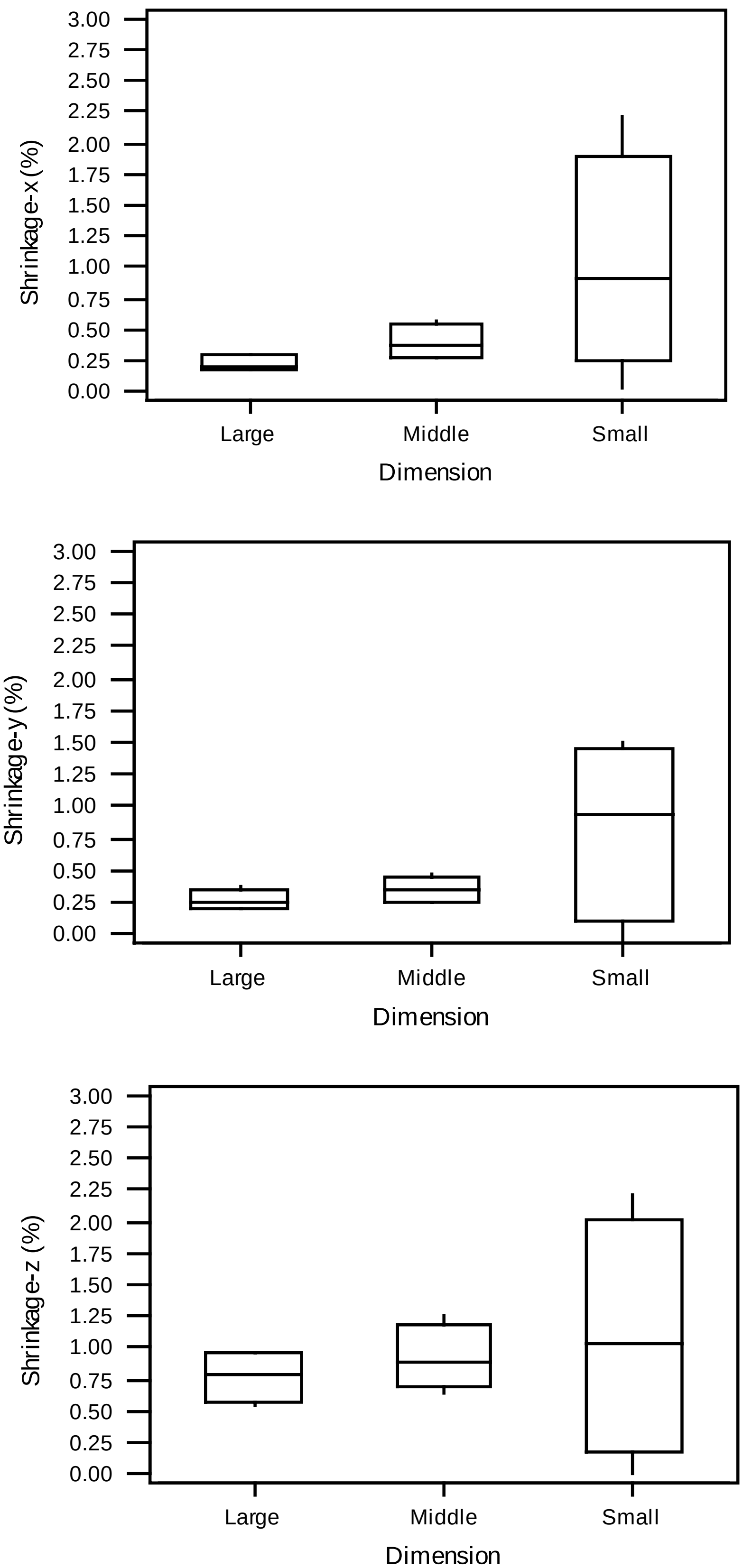


Figure 5. Shrinkage for RS2 over both furnace cycles for 800 torr, 80% infiltrant amount

The results for LaserForm ST-100 differ significantly from those for RS2.0. From Figure 6 it is apparent that there is no significant difference in shrinkage based on infiltrant amount. From Figure 7 it can be seen that ramp rate does have a significant effect on percent shrinkage. Both of these results are different from the results when using RS2.

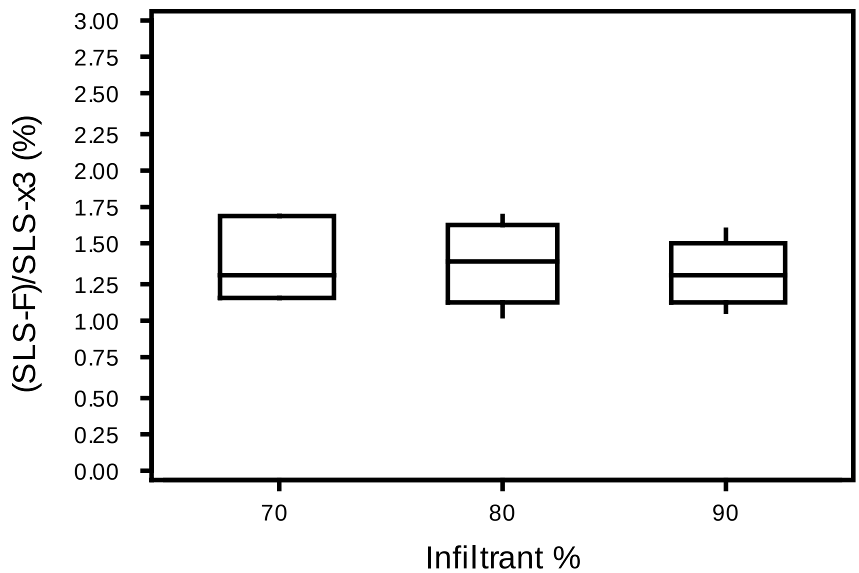


Figure 6. Difference in percent shrinkage based on infiltrant amount during ST-100 furnace run. (Large x-dimension.)

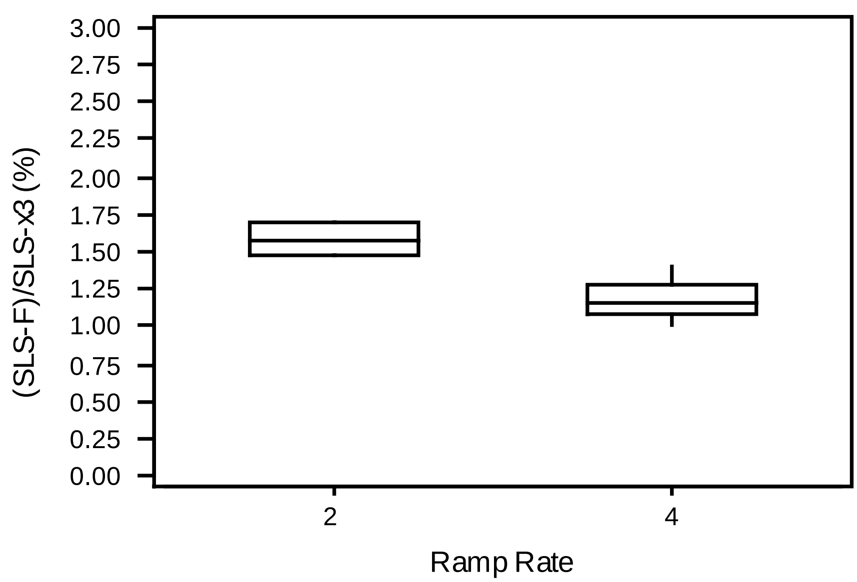


Figure 7. Difference in percent shrinkage based on ramp rate during ST-100 furnace run. (Large x-dimension.)

Figure 8 shows the overall shrinkage in the x, y and z dimensions for the ST-100 furnace run at 800 torr, 80% infiltrant amount and 4°C/min.

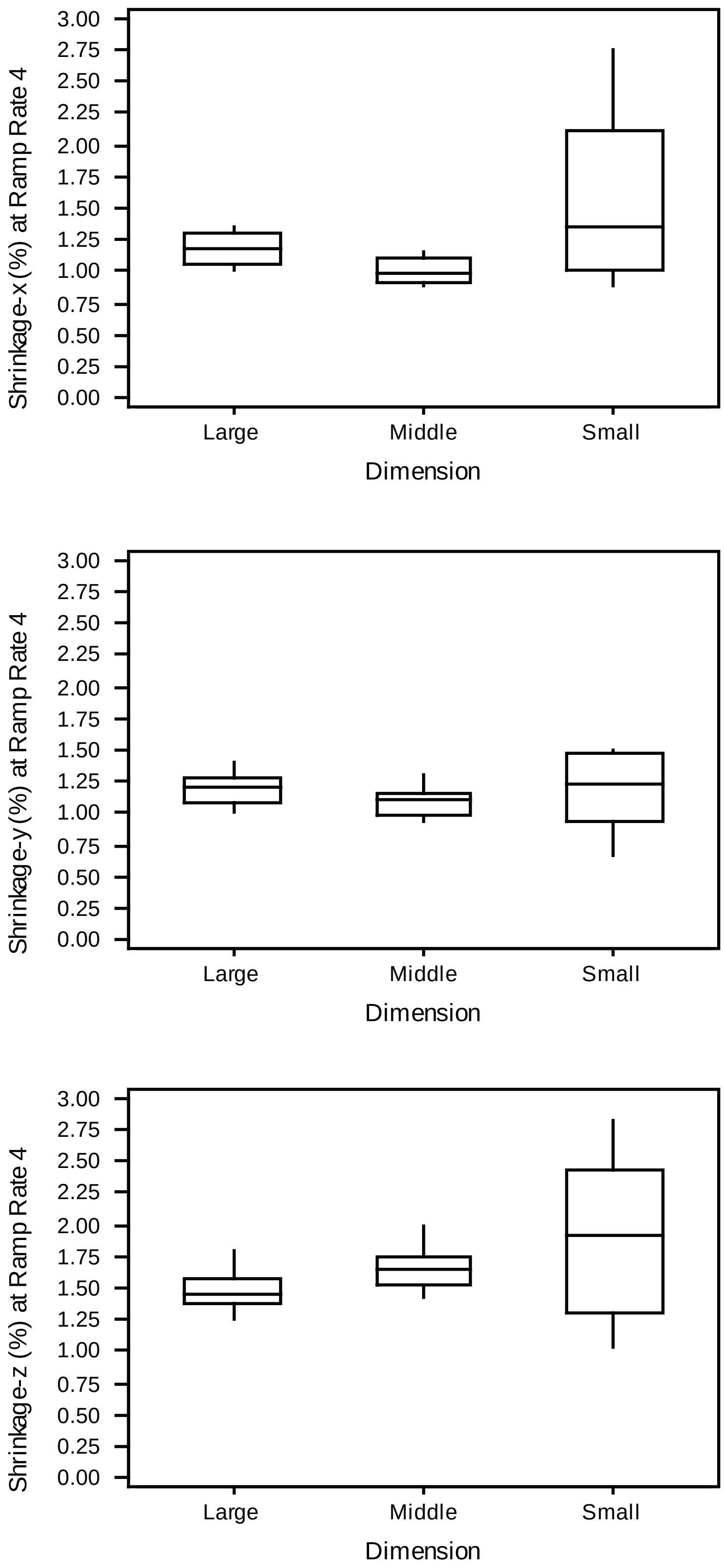


Figure 8. Shrinkage for ST-100 for 800 torr, 80% infiltrant amount 4°C/min.

## SUMMARY & CONCLUSIONS

A brief synopsis of the differences we have found between LaserForm ST-100 and RapidSteel 2.0 thus far is:

- ST-100 is sensitive to ramp rate whereas RapidSteel 2.0 is not.
- ST-100 is insensitive to infiltrant amount at the levels tested, whereas RapidSteel 2.0 is.
- Shrinkage in ST-100 is more uniform between the x, y and z axes, when compared to RS2.
- ST-100 has better feature definition (crisper corners) and better surface finishes than RS2.
- One furnace cycle speeds up the process dramatically, but its effect on the variation in shrinkage has not yet been determined.
- Absolute shrinkage for ST-100 is significantly greater than for RS2.

The inclusion of fine particles in ST-100 is the main reason ST-100 behaves differently during furnace processing than RS2. The fine particles enable sintering to begin at lower temperatures and continue over a broader range of temperatures. Sintering in RS2 occurs fairly uniformly at the sintering temperature so the ramp rate used to get to that temperature has an insignificant effect on the shrinkage. For ST-100, sintering begins to occur before the infiltration temperature is reached and the longer it takes to raise the temperature from the onset of sintering to the infiltration temperature, the greater the sintering shrinkage.

It is not clear why infiltrant amount is a significant factor for RS2 and not for ST-100, but it may be due to the difference in infiltrant amount levels between the two.

Based on initial results, a furnace cycle that would minimize shrinkage would be one that heats the part as quickly as possible, holds for the minimum time necessary for infiltration to occur and then cools slowly to avoid warpage.

Further data analysis and experiments will be performed on the ST-100 material in order to better determine optimum furnace processing parameters.

## ACKNOWLEDGEMENTS

The support of the following Rapid Manufacturing Center member companies is appreciated.

DTM Corporation
Gillette Corporation
GE Plastics
Optomec Design Company
Infinite Group (Advanced Technology Group)