Wax Pattern Making: Can Variation in the Wax Make a Difference?

by Jeffrey Rich, Vice President, MPI, Inc.

It is astounding that investment casting has been around for some 5,000 years, yet we still have trouble consistently making high-quality wax patterns. Of course, for those who understand the nuances of wax and wax injection, the problem is clear. However, for those who still live in the dark ages of investment casting and think of wax injection as nothing more than a wax pump, the answers are a bit more elusive. Wax pattern quality is dependent on a litany of variables, and making the perfect pattern every time can seem like pure luck or even black magic. Truth be told, it may be impossible to get a perfect pattern every time, but with a process that is in control, it is possible to get predictable results from each injection.

The measure of a quality wax pattern falls into two categories: visual and dimensional. Both categories are impacted by the manipulation of process input variables. The variables commonly accepted as "key" to the process are wax temperature, wax pressure, wax flow rate, die temperature, and dwell time. Additionally, there are variables that are beyond the operator's control or difficult for the operator to affect. Some of these variables are batch-to-batch variations in the wax, settling of fillers, nonhomogeneous wax temperature, air in the wax, and characteristics of the die (feed, flow path, venting of air, etc.). Environmental conditions may also affect the pattern-making operation, such as wax room temperature and humidity. The ICI Process Control course teaches that the best way to achieve a predictable output from any process is to control the key process input variables. As you can see from the above list of process input variables for wax injection, several are likely important, but they are not under the control of the operator.

Recently, MPI's Pattern Production department experienced shifts in dimensional characteristics that appeared to coincide with changing from one batch of wax to another batch. This dimensional change in the wax patterns negatively affected the automated assembly process, in some cases bringing assembly to a stop. MPI conducted an experiment to look specifically at the impact of batch-to-batch wax variation and the impact that such variation has on the dimensional stability of a part. Wax manufacturers provide wax with specific properties, which are documented and supplied with each order of wax. Some of these properties include ring and ball softening point, specific gravity, congealing point, melting point, ash content, thermal expansion, viscosity (usually provided at a given temperature), and recommended injection temperatures. Each of these properties has its own acceptable tolerance. The question was, could a variation within the wax manufacturer's properties tolerance cause a change in the process output resulting in bad wax patterns?

Experiment Setup

- Select wax pattern
- Select wax
- Build a measurement jig to measure sink (cavitation) in wax pattern
- Conduct measurement system analysis (MSA)
- Conduct experiment - Measure multiple patterns from multiple wax batches
- Analyze results

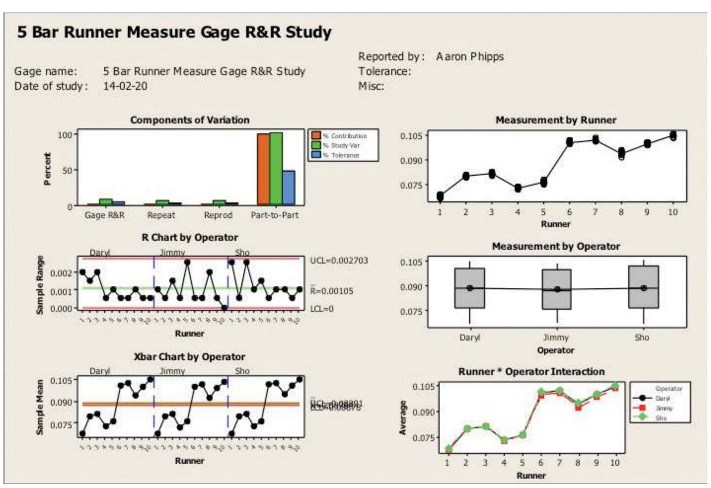


Figure 1: MSA-graphical results

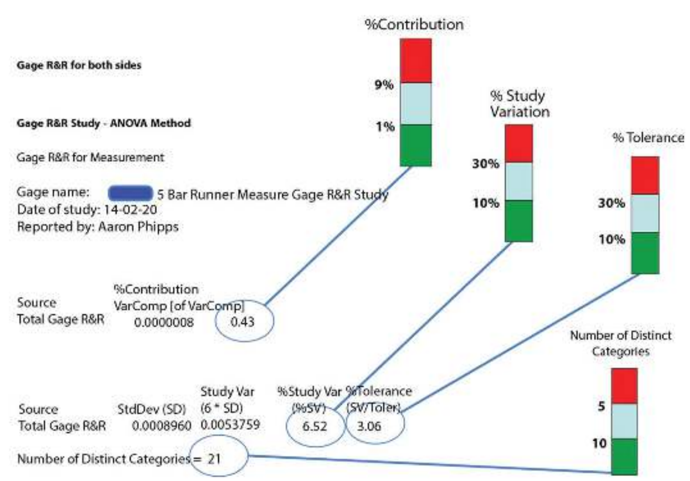
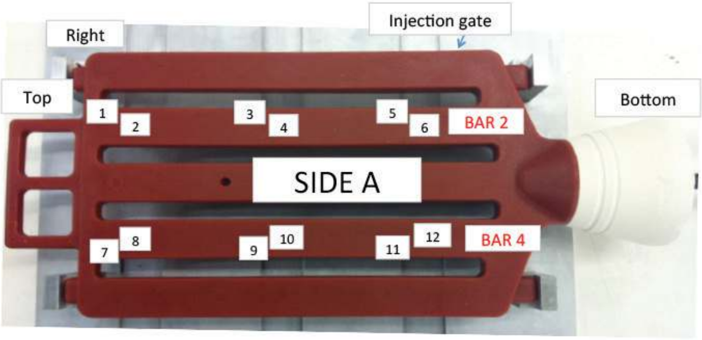


Figure 2: MSA-statistical results



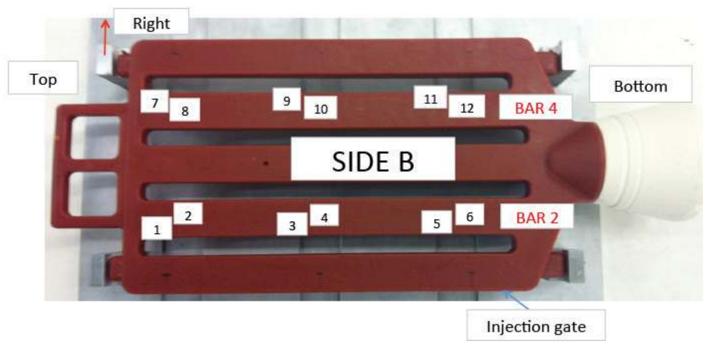


Figure 3: Pattern Side A

Figure 4: Pattern Side B

For experimental purposes, MPI selected a five-bar injected runner and a reclaimed wax. Each batch of wax met the same quality standards and was within the manufacturer's acceptable specifications for each property tested. MPI designed and manufactured the jig. Next, an MSA was performed to prove that the measurement system would provide high-quality, reliable data. MPI did not want the total process variation to be significantly influenced by the variation in the measurement system. The MSA used standard protocol: five parts, ten measurements, three operators, and three randomized replications. The data was analyzed using Minitab statistical software and the results showed a very robust (repeatable and reproducible) measurement system (**Figures 1** and **2**).

In the experiment, MPI Pattern Production measured four different batches of wax, taking measurements from 12 points on each side of the wax pattern (two-sided) for a total of 24 measurements per pattern, or 120 measurements per wax batch (**Figures 3** and **4**).

The wax patterns were all injected using the same injection parameters on the same die on the same MPI wax injection machine. The recipe used a wax temperature of 123°F, wax flow rate of $4in^3$/second, wax pressure of 450 pounds per square inch, injection time of 200 seconds, and a die temperature of 60°F. MPI performed several different methods of quantitative analysis on the measurement data, including ANOVA, 2 Sample T-Tests, descriptive statistics, and normality testing. Additionally, MPI reviewed several types of qualitative tests, including histograms, box-plots, and scatter plots.

After reviewing the data it was determined that, the first batch of wax was statistically different from the other three batches. The three other batches were statistically the same. No individual batch was statistically the same as the first batch. The conclusions were drawn from hypothesis analysis using ANOVA of all four batches and multiple runs of 2 Sample T-Tests for each batch against all other batches. The box-plots of the measurement data also illustrate this (**Figures 5** and **6**). Note the distinct pattern in the first batch, compared to the more random measurements in the second batch. Batches 3 and 4 were so statistically similar to batch two that they are not shown separately. While we intuitively had known for years that the batch-to-batch variation in the wax causes significant variation in the wax pattern, up to and including causing bad parts, it was exciting to have solid evidence. Now we wanted to know what had changed in the wax enough to have this much variation show up in the wax pattern.

It did not take long to determine the culprit. The wax manufacturer had provided all the standard properties

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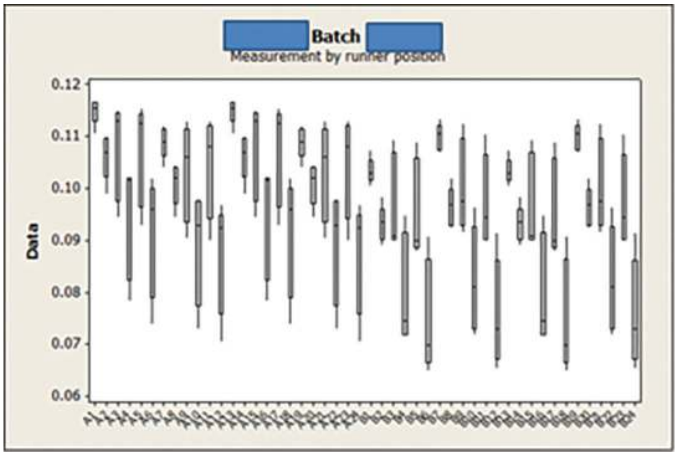

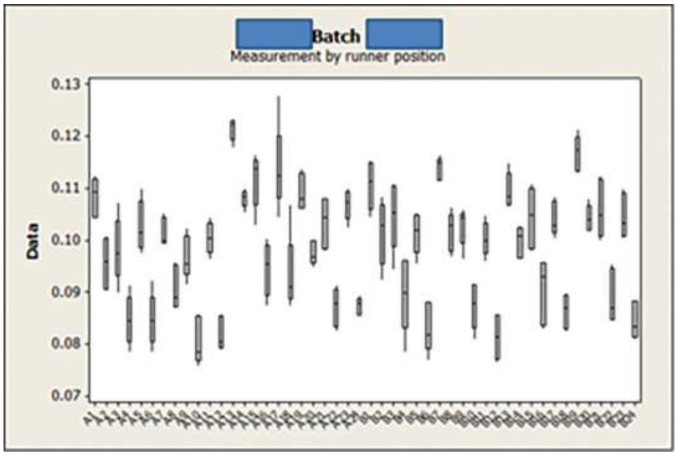

Figure 5: Batch 1 Measurements

Figure 6: Batch 2 Measurements

and tolerances for the wax. Each batch had some variation on some of the properties, but all were within the specified tolerances. MPI had requested full viscosity curves for each wax to include the paste range (see Figure 7). The difference in the batches showed up in the viscosity curves. Based on the information provided by the manufacturer, it is impossible to determine why the shift in the viscosity curves occurred. It is clear that the wax from batch 1 resulted in statistically different patterns than did the other three batches of wax. The viscosity curves for wax batches 2, 3, and 4 showed only minor variations, specifically at injection temperature.

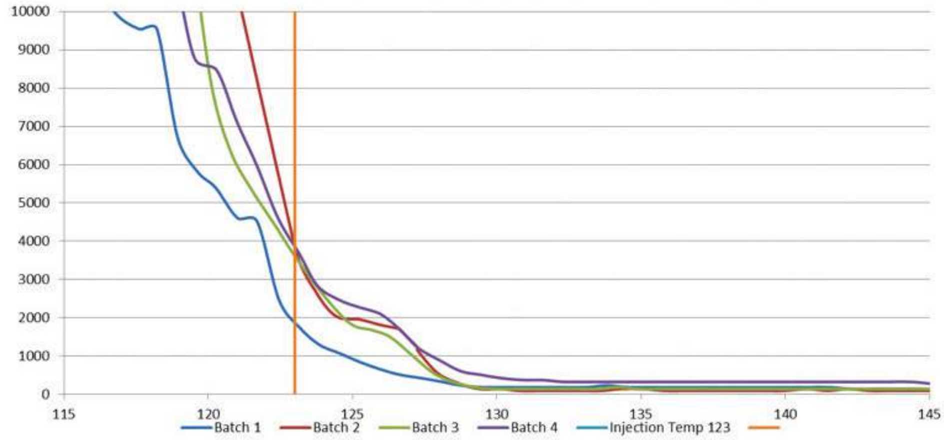

Figure 7: Test Wax Batches Viscosity Curves

Statistically speaking, we are dealing with two different waxes. The properties measured and advertised by the manufacturer met the tolerance specifications, yet they were not truly the same wax. This is cause for concern if you are striving for a highly controlled process. To help ensure that you understand the potential variation a given wax batch will have on your process, it is important to require the wax manufacturer to provide the full viscosity curve. Pay close attention to the wax viscosity at the injection temperature. If a new batch of wax indicates a viscosity change at your injection temperature, you should anticipate a change in the quality of the injected pattern. This could be manifested as a dimensional and/or visual quality change in the injected pattern.

MPI recommends that foundries require wax manufacturers to provide the viscosity curve for each batch of wax. By comparing the viscosity curves, you can determine the wax viscosity at your desired injection temperature. Your wax room engineer can use this information to help optimize your injection parameters. In our industry, process optimization through process control has become critical to remain competitive. For more than 60 years, the investment casting industry has had as its goal the production of "near net shape" castings. Unfortunately, secondary machining operations remain a given and necessary additional expense. As the tolerances of the delivered parts to the customer have become tighter and tighter, casting the part with little to no machining has grown even more difficult. The demand for the efficient production of finished parts has increased. The wax pattern is instrumental in delivering that casting. It makes sense that the industry should focus on continuous improvement in the wax room and process controls that now allow us to make "net shape" wax patterns part of the goal. In order to continue to be a viable, profitable industry, we must strive to improve every area of the casting process and to educate ourselves on how to control our processes and eliminate variations, even in areas never before considered. Competition continues to drive more and more automation into the wax room, and automation demands the reduction of variation beyond the previously accepted tolerances in materials, equipment, and production.

The more your operators and wax room engineers understand the process and the effects of wax variation, the more likely you are to produce perfect parts every time—or at least most of the time! The ICI Process Control course teaches the importance of reducing variation in all aspects of your process. I hope this experiment helps illustrate the critical nature of process control and shows that variation can exist anywhere in your process.

About the Author

Jeffrey Rich is the vice-president and general manager of MPI, Inc. Rich is a Six Sigma Master Black Belt and has used the tools of variation reduction and lean manufacturing as an executive at General Electric and Textron. He has brought those skills to MPI, where he champions manufacturing and equipment innovations that have improved MPI's ability to manufacture and deliver high-quality equipment to take advantage of the industry's leading process control standards. Rich participates in the ICI Process Control course as an instructor and has recently accepted a position on the ICI Education Committee.

About MPI

MPI is a leader and innovator of wax room equipment, featuring a broad range of wax injection machines that generate higher casting yields with increased productivity and throughput. As the acknowledged leader in wax room innovations, MPI has developed and introduced more systems and products than all of its competitors combined.

In addition to producing industry-leading wax injection systems, MPI offers total wax room automation, from wax injection to wax assembly, using integrated robotics technology. Automation also allows MPI to cost effectively provide pattern and assembly services, which can be shipped directly to their customers. A world-class customer service team featuring the Global Support Services program backs all MPI equipment. To learn more about MPI, visit www.mpi-systems.com.