Digital Technology Makes Strides In Investment Casting Wax Room

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Until the introduction of digital technology, only minimum controls were available in the investment casting wax room. Since digital controls are now an option, operators can visually see what is happening with the wax temperature, flow, and pressure each and every injection.

Digital technology allows tighter tolerances, less variability. No matter how sophisticated the instrumentation, however, the application of that instrumentation and how it is used to control the process is the real challenge. This article will review the information available with digital controls and how it can be applied to reduce wax room scrap and achieve higher casting yields.

Key input variables are temperature, flow, pressure, time and the wax itself.

Manual Control

Not long ago, investment casters were dependent on manual controls in the wax room (see illustration 1). And if there is one thing consistent about manual controls, it is inconsistency.

Wax Temperature Control: Wax temperataure was loosely controlled using liquid filled, bulb type, on/off temperature controllers with swings of ±5° C being the norm. Setting the instrument varied by operator. Each operator would set the instruments differently depending on their vantage point or eyeball position to the instrument.

Wax Flow Control: There was no “Flow Control” device on the machine, no knob labeled flow control. Flow was controlled by the manually operated wax valve. The more the operator opened the valve the faster the wax entered the die. There was no flow read out– only the luck of the draw and the ability of the operator to repeat.

Wax Pressure Control: Manually adjusted non-compensated hydraulic pressure-reducing valves had large variations in pressure from cold to hot hydraulic oil. Pressure adjustment accuracy was again up to the vantage point of the operator. The wax pressure was used as a flow control device; the higher the pressure the higher the flow.

Die Temperature Control: There was no way to control the die temperature. In most cases there was no cold water even flowing in the platens. In fact, there were no platens. If cooling was required, dry ice was used on top of the die. It was common in the golf industry back in the 70’s to see soft metal or epoxy dies made in multiples being run in sequence. While one die was being injected, one die would be cooling using dry ice, while another would be having the pattern removed by the operator. Control of the die temperature was never considered.

Injection Time: There was no injection measure. The operator would count off time and establish a rhythm.

The Wax Material: There were also changes in the wax. The industry was forced to make some major changes when PCBs were removed from the wax. It took a while to get a wax pattern with a good surface finish again.

Digital Control

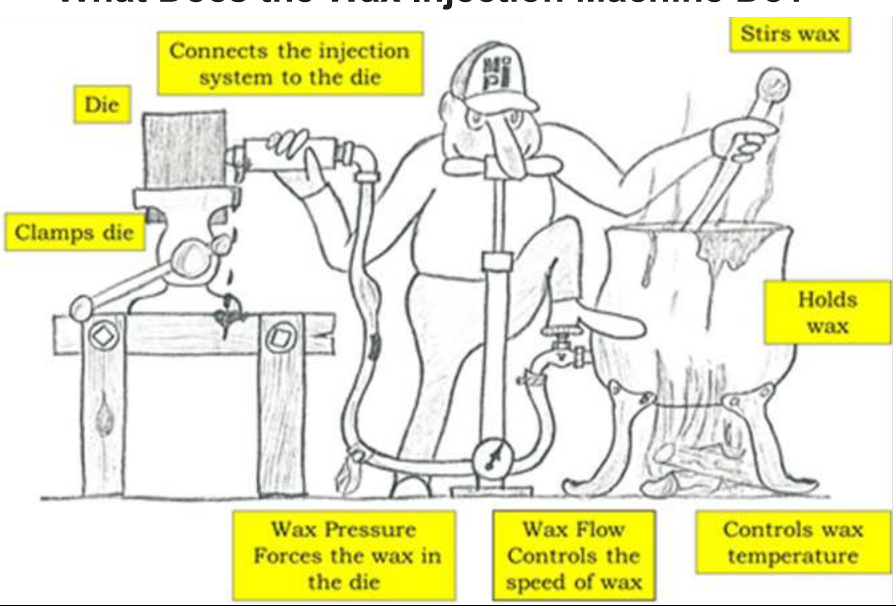
Digital Technology allows control of the key input variables – temperature, flow, pressure and time - accurately, thereby achieving dimensionally repeatable wax patterns.

The goal of wax injection is to replace 100% of the air that is in the die with wax. If this goal is achieved, the result will be a perfect wax pattern. Consistently reaching this goal requires control of temperature, flow, pressure, time and the wax itself - repeatedly.

Producing dimensionally repeatable patterns is the foundation to producing dimensionally repeatable castings.

Wax Temperature Control: Wax temperature controls viscosity, and viscosity controls the flow ability of the wax in the die. Today there are electronic temperature controllers, which are tuned to each temperature zone. The accuracy and repeatability of the instruments is extremely tight, less than +/-.5°C.

What Does the Wax Injection Machine Do?



Wax Flow Control and Wax Pressure Control: Flow and pressure are controlled with either electronically controlled hydraulic servo or proportional valves. The valve's position or opening is controlled by varying the input voltage through a programmable DC driver card. These devices are closed loop and they continually monitor and correct the flow and pressure during the injection cycle. Digital technology has allowed operators to see the interaction of flow and pressure in a graphical format. For the first time, an operators can see the relationship between wax flow and wax pressure live during an injection and for the first time they can adjust flow and pressure and understand the effects the change has on the wax pattern.

Die Temperature Controls: Wax injection machines are now available with closed loop temperature controlled water circulating in the platens and the dies. Wax enters the die as a liquid, and must be brought down in temperature to a solid before the pattern can be removed from the die. Operators now have control of the die temperature and the process of heat removal from the wax pattern.

"Why isn't every foundry with these controls creating perfect patterns?"

Injection Time: The current timer which is initiated by the automated injection cycle – may not be as accurate as the timers used in the Olympics, but it is a lot better than the operator counting.

Digital Technology allows all the key process control devices set points to be stored as part of the recipe. The operator simply loads the recipe from the machine's memory; no more variability caused by the operator during the setup of a new job.

Now, with all these digital controls opertors have the ability to control and analyze wax temperature, flow, pressure and time. Recipes can be stored so the process can be repeated on every shift with every operator. Investment casters have the ability to control who can make changes to the recipes. Any drift of the process, can be analyzed and brought back in line before it goes out of tolerance and makes a bad part.

The electronically controlled valves used for flow and pressure control, have the capability to be programmed to vary the flow and pressure during the injection cycle offering the ability to fine-tune a complicated injection profile - such as injecting around a fragile ceramic core for a single crystal turbine blade. The controls have the ability to produce a perfect pattern each time.

Why isn't every foundry with these controls creating perfect patterns? Why haven't pattern defects been eliminated? In order to achieve these results, the wax department must understand the interaction of the key input variables and implement rules for managing this technology. No matter how sophisticated the instrumentation is, the application of that instrumentation and how it is used to control the process is the real challenge.

How can an investment caster know a wax injection machine is doing what it is supposed to do? Are certain jobs dedicated to a particular wax injector because a job runs better on one machine than another? This is a production nightmare because one job cannot be switched from one machine to another. How can one manufacturer's machine be compared to another when different manufacturers apply these controls differently? For instance, one manufacturer will monitor and control the wax pressure in the wax and another manufacturer will control the wax pressure in the hydraulic system. How does the operator know that what is set on a machine is in fact what is coming out of the nozzle?

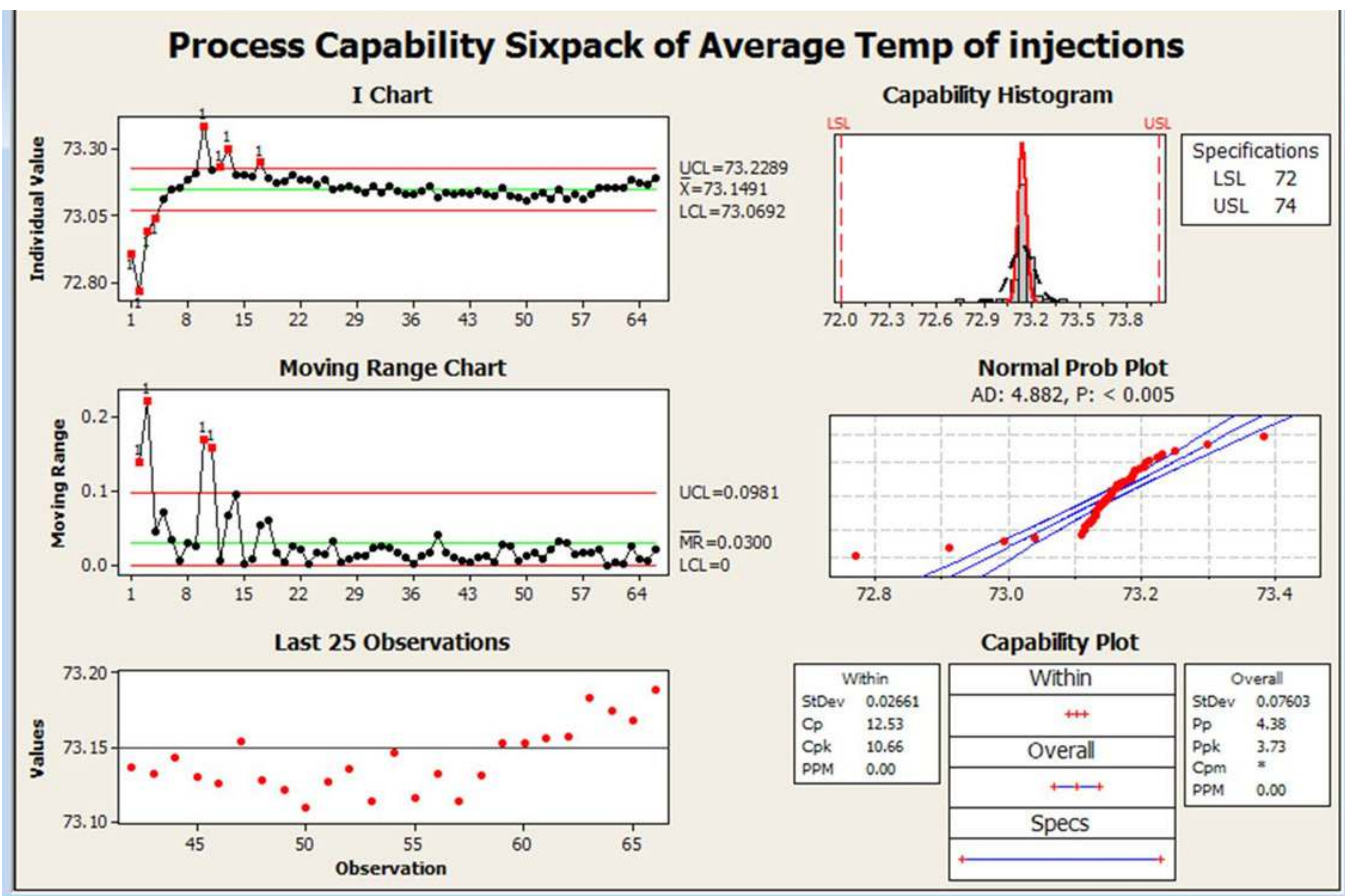
Now through the use of digital data collection devices, such as MPI's 20-20 Process Vision, real time wax temperature, flow and pressure can be gathered for each injection, from any manufacturer's machine and differences compared from machine to machine. The data the 20-20 collects from each manufacturer's machine is the same no matter how the manufacturer controls its machine. Known offsets can be entered into the machines and make all machines match. Thus, the "personality" of machines can be eliminated and get repeatability can be achieved from all of machines.

Here is an example of how a large foundry benefited from the use of a data collection device. The foundry had several injection machines ranging in vintage from five to 40 years and from different manufacturers. The newest included a digitally controlled wax injection machine.

They used an engineer to collect injection data using MPI's 20-20 Process Vision digital data collection device and compared each machine's pattern quality and repeatability. They saw machine-to-machine variability and variability within each machine. They rebuilt one of the older manual machines, brought it back to its "as new condition" and reduced the variability. They then compared the digital data from the rebuilt machine to their newest electronically controlled machine and were able to make informed decisions, based on real injection data, as to what would give them the best ROI.

In the above example, one of the data points being collected was the wax temperature. They used the data collected to analyze, through statistical process control, the wax temperature variation at the nozzle. Using the data set for one machine and a run of 66 injections, the customer performed a statistical process control analysis. The data was gathered at intervals of every .1 second for the duration of each 9-second injection. The average of each sample was taken and then used to make the SPC chart below.

The graphs and the last 25 observations indicate the process is mostly in control and stable. This customer evaluated the specific special cause variations at the beginning of the run and determined the cause was due to the machine sitting idle for a time period. This machine did not



have fixed purge of the injection nozzle and suffered from wax changing temperature in the nozzle. After numerous evaluations, the customer determined the value of adding fixed purge and has ordered all new machines with that feature.

Further analysis of this data using both the histogram and the capability information clearly shows the process is very robust and can meet their requirements of plus or minus one degree Fahrenheit. It would be prudent to also analyze the other special cause variation injections to see if it can be determined what caused that variation.

This six-axis robot can load the core, unload the pattern and perform secondary operations normally done by an operator, but without operator variation.

Use Data to Drive Recipe

For years, engineers have been frustrated with the inability to accurately predict the outcome of a wax injection recipe. The best way to start injecting a new part is to take the recipe of a similarly sized part already in production. From there the recipe is adjusted to achieve an acceptable part. What should be done if the final part has a dimensional variance from specification? How about do a 2k full factorial design of experiment (DOE) to develop a dimension prediction formula? One of MPI's customers recently conducted just such an experiment.

The customer provided a die and wax to conduct the experiment. Five factors were analyzed and all data was collected to perform the DOE. The length and width of the part was evaluated under the various parameters and a formula developed that can accurately predict the length and width for various combinations of the factors. The factors evaluated included: wax temperature, flow, pressure, die temperature and dwell (hold) time. Each factor was established by selecting a high and low value that when used produced a visibly good part.

From this data, predictive models were developed. Imagine the value gained by being able to accurately predict how changes in your recipe will affect critical dimensions on parts. Without digital equipment capable of maintaining the low level of variation, this type of experiment is not possible.

Train personnel

Having personnel adapt to the new digital technology of the wax room is key to success. They need to be properly trained in the operation and maintenance of equipment. They need to understand how a new digitally controlled machine differs from the older machines. It is very often difficult for an operator to give up his old ways without understanding why. In fact, the wax machine with the newest controls has sometimes been set like the older equipment in the wax room because an untrained operator was given access to the program and could make changes to the recipe.

Example #1: Oftentimes in older machines, the accuracy of the temperature control of the injection nozzle was nonexistant. To overcome this nozzle temperature difference, the operator increased the nozzle temperature to achieve a more accurate wax temperature. The operator through experience made the decision to increase the nozzle temperature and determined how much to increase it. It was the operator controlling the temperature, not the machine controlling the temperature. This was the norm; this is what was required of the operator. In the new digitally controlled machines, if operator changes the temperature of the nozzle, as he is acccustomed to doing, he is actually throwing the machine out of control– introducing a temperature variable, which is producing a pattern-to-pattern variation. The machine is not being used as it was designed. To overcome this, access to the process controls should be given only to someone who has been trained and understands how the new machine is meant to function.

Example #2: Management purchases a machine that has paste capability and has projected an ROI based on cycle time reduction. The machine is installed in the wax room with operators accustomed to using liquid wax machines. The operator, who does not know about the benefits of paste wax and the testing that was done to achieve the cycle time reduction, use it as a liquid machine with no cycle time improvements. Parts are being made; they are good parts, but they have not benefited from the projected ROI because the cycle time has not been reduced. Again, the machine is not being used as it was designed.

Example #3: The wax pressure control graph is showing spikes, an over pressure spike, at the beginning of the pressure curve. Chances are the operator is not able to analyze this information. The spikes mean that the machine is controlling the flow by pressure - which gives variation in the flow or an unstable flow curve. The operator should be able to get the machine into flow control mode, but they must be trained to understand the meaning of the data the machine gives them.

Robotic Integration:

So far, discussion has centered on digitization of the wax injector. There are other areas in the wax room where digitization can improve the wax room process: through the use of robots.

Investment casters are perhaps most-familiar with the use of robots in the shell room– how they have reduced manual labor and added repeatability to the shell-building operation. Robots have now entered the wax room and they are here to stay. Robots reduce labor and improve the pattern-to-pattern repeatability as well as the assembly-to-assembly repeatability.

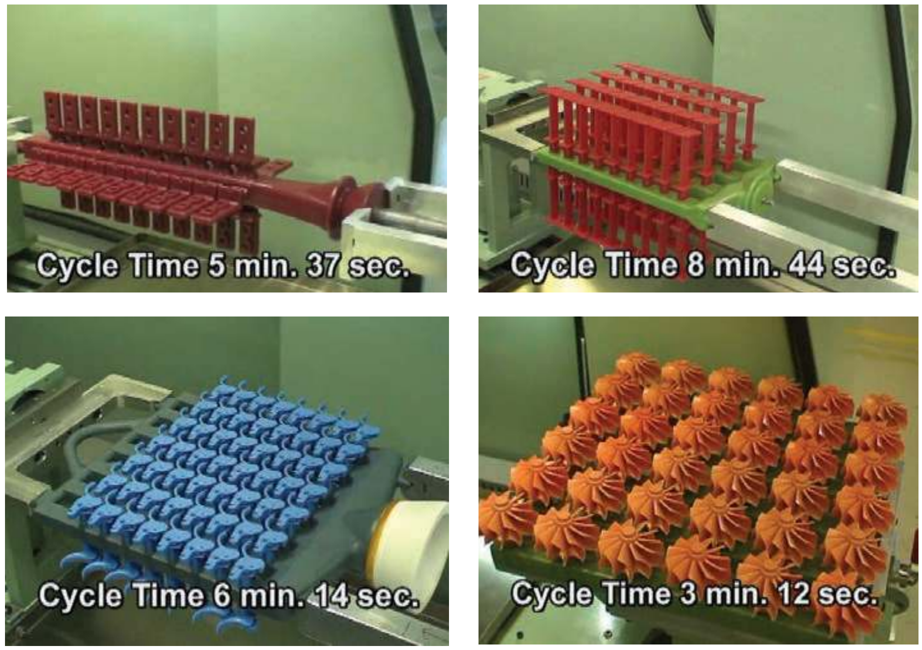
Another area of digitization is an automated wax injection cell, which combines the accuracy of the digitally controlled wax injector with the accuracy of the digitally controlled robot. The robot can load the core, unload the pattern and perform all secondary operations that are normally done by an operator with the advantage of removing the variability of the operator. Not only is the same operation done each and every time, but the time it takes to do the operation is repeated. If the machine is set to perform in 1 minute 52 seconds, it does so every time. It is boringly accurate.

Because of the accuracy of the robots and their ability to work together, more patterns per runner bar can be assembled and more accurate assemblies can be created than what can be done manually.

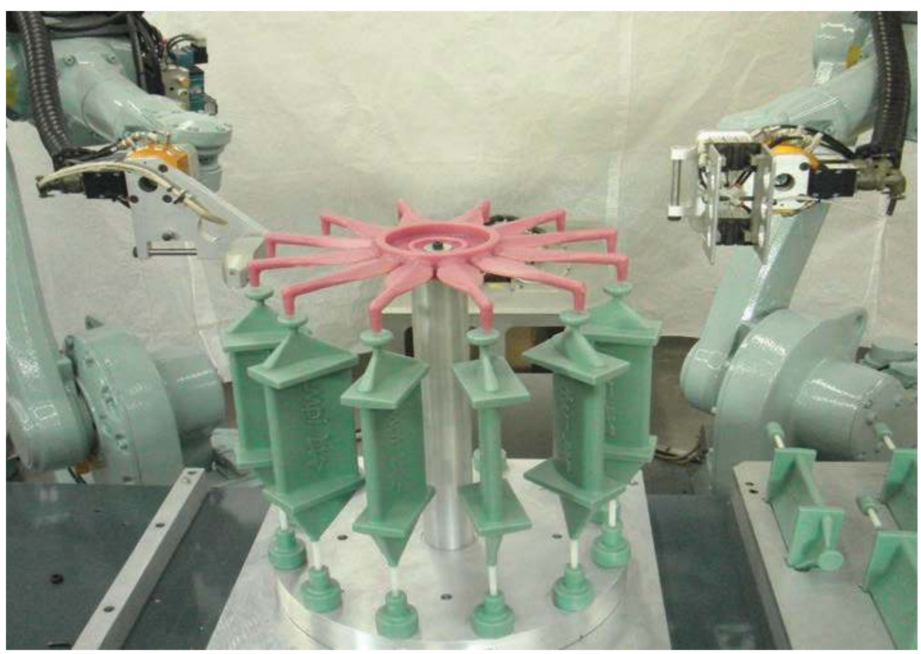
There are other applications where robotic assembly offers significant advantages even when assembling only one pattern at a time. For example, a single crystal turbine blade assembly is created as a circular assembly with the blades positioned radially around the downpour. In order to achieve repeatable single crystal grain growth it is critical that the radial and angular position of the blade and the position of the baffling around the center downpour are accurately positioned. The electronically controlled robots can accurately position the patterns to create that position and angle for each and every assembly. The results are a much higher metal casting yield of single crystal turbine blades.

Conclusion:

Wax injection and pattern assembly is just coming into the spotlight of the digital age. Once embraced and correctly applied, the technology correctly, the technology truly control the process, and result in huge gain to increase the bottom line through casting yield improvements.



With pattern assembly using robots, more consistently accurate patterns can be included in each assemly.



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