Technical Paper

# Overcoming Common Wax Injection Problems: The First Step toward Automation

Featured in March 2016 Issue of InCast Magazine

Presented during the 14th World Conference in Investment Casting
Paris, France
April 18, 2016

Aaron Phipps
VP of Sales and Marketing
Technology Center Manager
MPI, Inc.

Jeffrey Rich
VP of Operations
MPI, Inc.

## Abstract

A requirement for automated injection of wax patterns is the ability to make defect free patterns. MPI has collaborated with two US foundries in 2015 to demonstrate how quality dies combined with the proper application of process controls can eliminate common wax injection defects. Demonstrated results have shown significant reduction of scrap in the wax room, increased throughput and higher casting yields. The results were a dramatic reduction in scrap, reducing both operating costs and rework costs while dramatically increasing throughput. In both cases, the customer realized a corresponding casting yield increase. In one of these cases, the success of eliminating scrap from the wax injection process opened the door to automation of the wax injection of this family of parts. Where applicable, the ICI Atlas of Wax Pattern Defects, REVISED 2ND Edition as well as the ICI Process Control course materials is referenced.

Experience has demonstrated the correct application of process controls may eliminate wax injection problems. High-level control capabilities, combined with training on how to properly troubleshoot these problems and a good understanding of how to modify current processes will mitigate or even eliminate the problem leading to increased productivity, decreased scrap and casting yield gains. Capitalizing on these findings demonstrated that the improvements in pattern injection allowed work to be moved from an operator controlled manual or semi-automated process to a fully automatic injection process with little to no operator involvement.

## Introduction

This paper serves as an extension to another technical paper written for the Investment Casting Institute's 62nd Annual Technical Conference and Expo held in October 2015. The first paper *Current Problems In The Wax Room And How They Are Best Overcome* (https://www.mpi-systems.com/white-papers.php#.VpQWA43rtwU ), which focused on using injection parameters to overcome common wax patterns defects. The paper illustrated the value of high process control, having a capable and well maintained injector and understanding how to troubleshoot and apply proper techniques to optimize the die. The approach to the subject die for this paper was initially the same as the subject die in the earlier paper, but produced markedly different results.

Lamothermic Precision Investment Casting Corporation of Brewster, NY (hereafter referred to as the foundry) has for many years partnered with MPI on various projects. The foundry was interested in how to best take commercial, low volume parts and automate them in the wax room. The belief has always been this is not commercially viable due to tooling costs, not to mention the capital expenditure to purchase automation equipment. The foundry chose a low volume die known to produce a high scrap rate and asked us to attempt to automate the injection and assembly. Step one to automation of the injection process is to have a die that makes defect free patterns. As seen in the paper *Current Problems In The Wax Room...* many wax pattern defects can be overcome using the techniques mentioned in the paper (die optimization). However, as illustrated in this paper, there may be times when die optimization alone does not allow for defect free pattern injection. The foundry's die proved to have mechanical anomalies that required further investigation and modification to overcome the defect of entrapped air.

MPI, with the full collaboration of the foundry, set out to conduct the required experimentation to see if this die could in fact produce defect free patterns. The experiment results are contained within this document. The results are analyzed and put to the test.

## Background

The test die is capable of running on a horizontal automatic press. It is a standard two-piece die with ejection pins allowing the part to fall out of the die into a water bath. It contains one slide block that make four holes in the part. The die typically produced between 45 and 55% defective parts. No data was captured on the quantity of parts that could be used with some repair. Defective parts were mostly just remelted for another injection. The process was largely untended on the automatic press, but was time consuming due to the requirement to inspect every part. While the part produced a variety of defects, by far the most common was entrapped air.

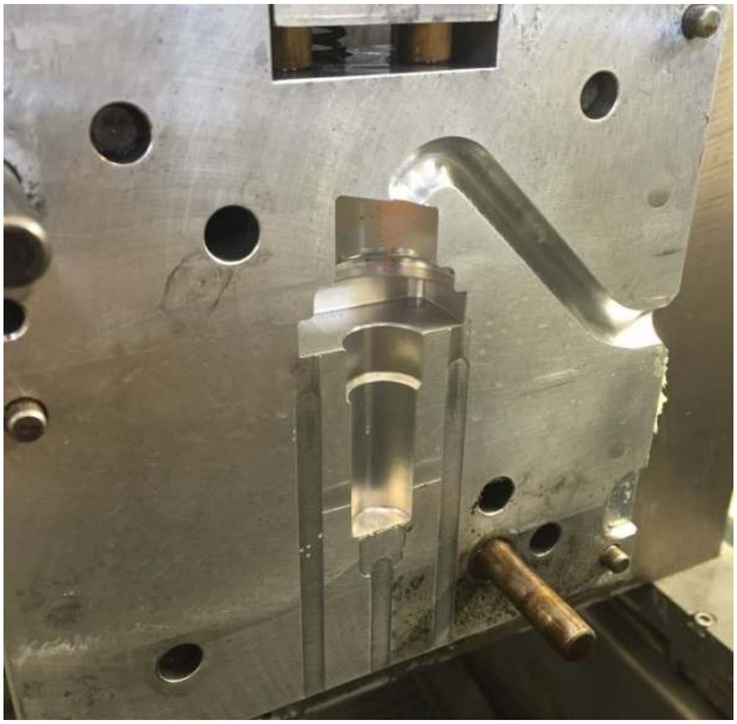
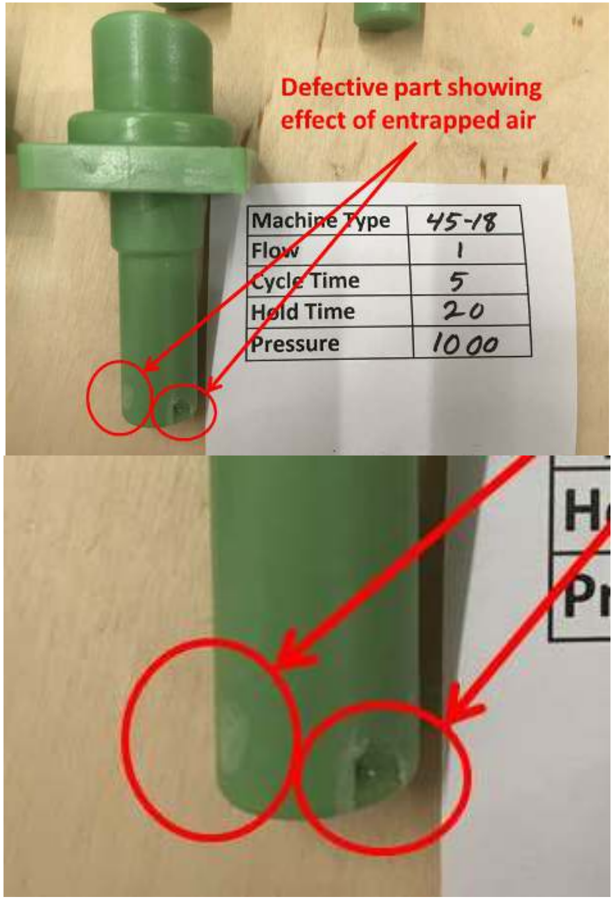


*Figure 1: Die*



Defective part showing effect of entrapped air

| | |
|---|---|
| Machine Type | 45-18 |
| Flow | 1 |
| Cycle Time | 5 |
| Hold Time | 20 |
| Pressure | 1000 |

*Figure 2: Defective Part*

## Experiment 1 Plan

The team had to determine an effective method to mitigate or eliminate the defects. The die was moved to the MPI Technology Center to be injected on injection equipment allowing for a high level of process control and statistical capability. This was determined and demonstrated in the paper Current *Problems In The Wax Room….* Multiple injections would be conducted in a production manner with data from each injection being captured on a portable injection-graphing unit. The injection graphing unit measures, records and displays real-time wax temperature, wax pressure and wax flow from any wax injector. The injection results are saved as CSV files for later analysis as well as graphed for real-time evaluation.

The following experimental data was collected and acted upon:

1) Conduct 40 injections using the foundry's die, wax and recipe. Capture injection data on the injection graphing unit to help with item 3 below, real-time evaluation of graphing and CSV files for later review.

2) Evaluate each pattern for quality and document the inspection results.

3) Conduct die optimization based on item 2 making injection parameter adjustments to improve pattern quality using data obtained from the injection graphing unit in step 1, consulting the ICI *Atlas of Wax Pattern Defects* and practical experience.

4) After optimization, conduct another 40 injections collecting the injection data on the injection graphing unit.
5) Again, evaluate each pattern for quality and document the inspection results in the same manner as item 2 above.

The results of the experiment are then analyzed and the appropriate conclusions drawn and presented.

## Results of Experiment 1

While the die optimization proved effective in mitigating most of the defects and the scrap rate was reduced, air entrapment remained a significant problem. It appeared that the applied changes to flow had very little effect on the reduction of entrapped air. This is counter to anticipated results. In many cases, entrapped air is caused from turbulent flow of wax in the die and can be eliminated by reducing the flow rate. The turbulent flow will allow the wax to encircle an air pocket and solidify around that air pocket inside the die cavity. As the cavity fills with wax, the pocket remains trapped inside the wax and moves with the wax toward the end of the cavity. In some cases the air pocket remains inside the wax to the extent it does not show up as a defect. In other cases the air will remain entrapped and will either be a surface defect of the part once the part is removed from the cavity or, if completely trapped within the wax, once removed from the cavity, expand and either cause a defective bulge or actually blow out through the wax causing a defect. As previously mentioned, the level of turbulence and therefore ensuing entrapped air is often overcome by decreasing the wax flow rate. It was therefore decided to run the optimization at two different levels for flow. The experiment was performed at a high flow rate then at a low flow rate. While the cycle time was significantly improved, increasing the number of parts produced per hour, the defect rates showed that, statistically, the injection parameter alterations produced the same outcome. Changing the flow did not decrease the defect rate as expected.

The experiment had not sufficiently eliminated the defects and was therefore deemed unsuccessful. As such, it was decided that the die should be run on a different machine. As previously mentioned, the first machine was a horizontal automatic press. In this configuration, the die's parting line is vertically oriented. One would think this allowed the maximum ability for the air in the cavity to be replaced by wax during the injection cycle leading to no entrapped air. However, the injection runner enters the cavity from the top of the cavity as oriented in the press. To eliminate any possibility that the runner to cavity vertical orientation was enabling the entrapment of air it was decided to rerun the experiment on an injection machine with a different orientation. The experiment was then conducted on a vertical C-Frame semi-automatic press, orienting the parting line of the die horizontally, to see if there were any changes in the defect rate. The die orientation in this press is perpendicular to the horizontal press. The hypothesis was that the change in the die's orientation should cause the wax to fill the cavity in the die in a different manner and allow the air in the cavity to be displaced differently.

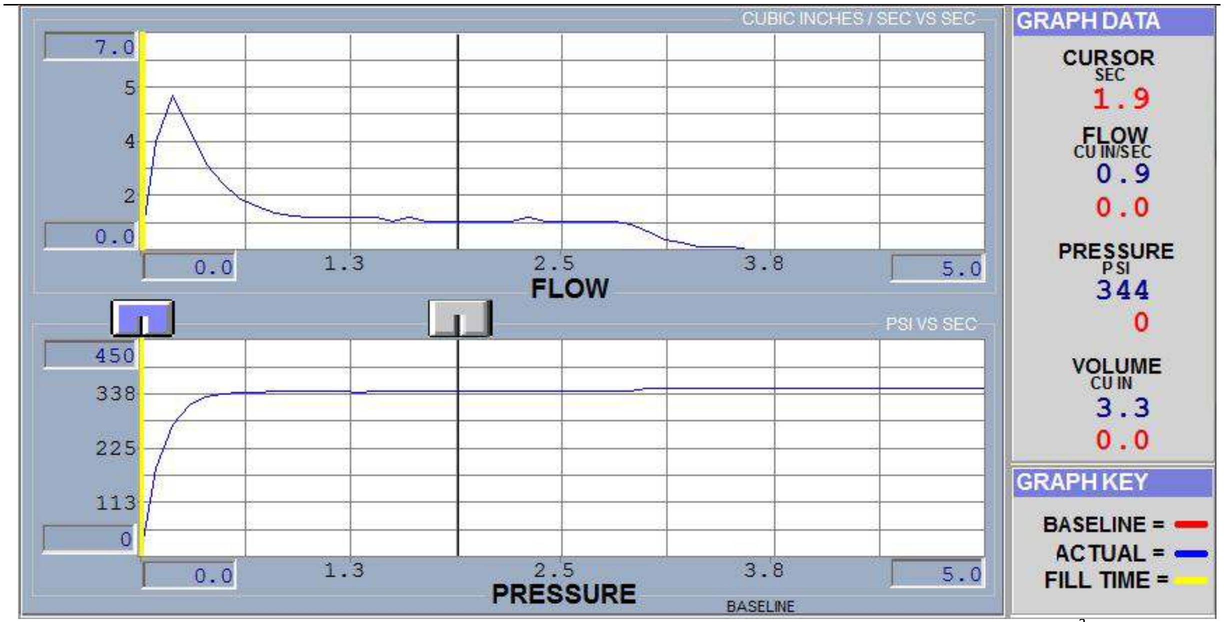
The experiment was repeated, this time on the vertical press with the die oriented horizontally. To our surprise and dismay, the results were virtually identical. We simply could not remove the entrapped air defect by changing die orientation or through further adjustments injection parameters. Additionally, the entrapped air continued to be an issue with both a low flow rate and a high flow rate. It became apparent that something in the die was causing the wax to trap air in a manner that it could not escape before the die was filled. A second experiment was devised to "see" where the problem was occurring during the injection cycle, thereby allowing a determination of how to overcome it.

*Table 1: Injection Settings and injection results*

| Machine (Horizontal and Vertical Injections) | | | |
|---|---|---|---|
| | | Optimized | |
| Injection Parameters: | Pre-Optimization | Low Flow | High Flow |
| Injection Dwell Time (seconds) | 50 | 26 | 26 |
| Wax Inj. Pressure (PSI/bar) | 350/24.1 | 700/48.3 | 700/48.3 |
| Flow (inches$^3$/cc$^3$ per second) | 13*/213* | 1/16.4 | 4/65.5 |
| Wax (degrees F/C) | 130/54.4 | 130/54.4 | 130/54.4 |
| Stationary Platen (degrees F/C) | 70/21.1 | 65/18.3 | 65/18.3 |
| Moving Platen (degrees F/C) | 70/21.1 | 65/18.3 | 65/18.3 |
| Injected Parts per hour ** | 59 | 99 | 99 |
| Defect Rate | 67.5% | 57.5% | 57.5% |
| Acceptable Parts per hour | 19 | 37 | 37 |

* This flow rate set point was never achieved - press was in a "pressure limited flow" state
See Figure 3 below

**Total cycle time including lubrication



CURSOR SEC 1.9
FLOW CU IN/SEC 0.9 0.0
PRESSURE PSI 344 0
VOLUME CU IN 3.3 0.0

*Figure 3: Flow and pressure graphs for Pre-optimization injections – Note flow set point was 13in$^3$*

The blue line in the graphs contained in figure 3 represent the actual flow (top graph) and pressure (bottom graph). This is a classic example of a machine set up incorrectly. The machine is operating in a “pressure limited flow” state. That condition exists when the set point of the pressure, which was 350psi and was achieved, is inadequate to reach the set point of the flow, 13in$^3$. Looking at the graphs you can see the machine initially tried to achieve the flow rate reaching a high point nearly 5in$^3$ momentarily and then dropping to a steady state rate of 1in$^3$ with the pressure at the maximum available for the injection, 350psi (based on set point). An appropriately set up machine would have the pressure set to a value that allows the desired flow to be achieved and also provides the correct pack pressure for the die once the cavity is full. When the pressure is adequate to achieve the desired flow the machine is in “flow control”. The first step in optimizing the die was to get the machine in flow control.

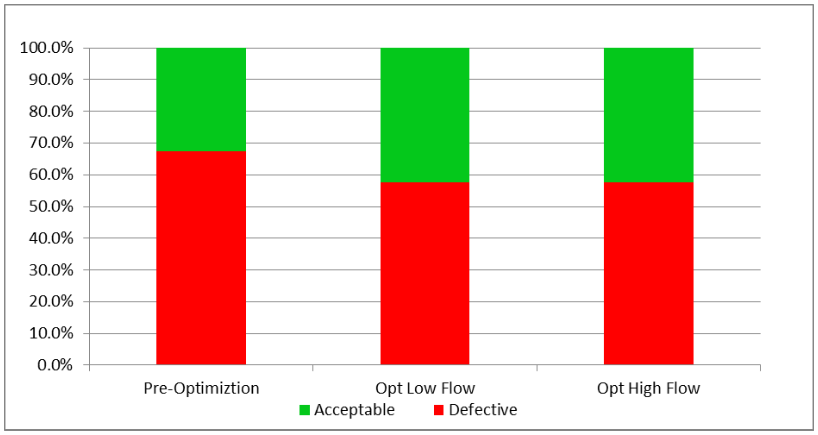


*Figure 4: Defect Rate – Pre-optimization and optimized*

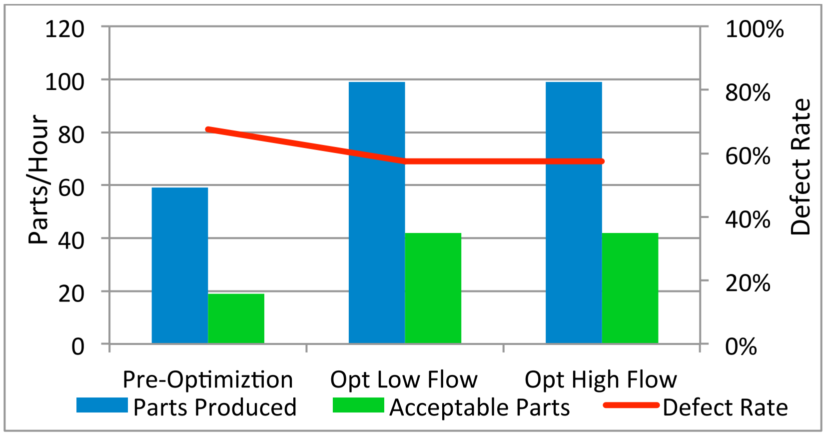


*Figure 5: Parts produced per hour Pre-optimization and optimized*

## Experiment 2 Plan

It was determined the best method to find the anomaly that was causing the entrapped air would be to use a series of short shots. Short shots are partial injections, where the injection process is started and then stopped at a set time interval prior to the completion of the filling of the cavity. Short shots completed at various time intervals allow a view of how the wax is entering and filling the cavity. With several short shots completed at different set times a complete picture of the cavity fill is obtained for analysis. Required process changes and/or die changes may be more apparent with this information.

The following experimental plan was followed and acted upon:

1) Set machine up using low flow rate recipe. (Note: high pressure is used to ensure the desired flow is fully achieved. Since the die cavity is not completely filled during the short shots the full pressure, commonly referred to as pack pressure, will not be seen by the die. This method assures flow control.)

2) Conduct five injections for each desired short shot set time. Set Times used were 2, 3, 4, 5 and 6 seconds.

3) Photograph the results of each short shot.

4) Set machine up using high flow rate recipe. (Note: high pressure may be used as the wax will not be packed and therefore the pressure used will only be that needed to achieve desired flow rate – flow control).

5) Conduct five injections for each desired short shot set time. Set Times used were 0.5, 1.0, 1.5 and 2 seconds. Note: the set times are different depending on where you want to see the wax and the flow rate. High flow rates require smaller time intervals.

6) Photograph the results of each short shot.

The results of the experiment are then analyzed and conclusions drawn and acted upon.

| | |
|---|---|
| Machine Type | 55-25 |
| Flow | 1 |
| Cycle Time | 2 |
| Hold Time | 20 |
| Pressure | 1000 |

| | |
|---|---|
| Machine Type | 55-25 |
| Flow | 1 |
| Cycle Time | 3 |
| Hold Time | 20 |
| Pressure | 1000 |

| | |
|---|---|
| Machine Type | 55-25 |
| Flow | 1 |
| Cycle Time | 4 |
| Hold Time | 20 |
| Pressure | 1000 |

| | |
|---|---|
| Machine Type | 55-25 |
| Flow | 1 |
| Cycle Time | 5 |
| Hold Time | 20 |
| Pressure | 1000 |

| | |
|---|---|
| Machine Type | 55-25 |
| Flow | 1 |
| Cycle Time | 6 |
| Hold Time | 20 |
| Pressure | 1000 |

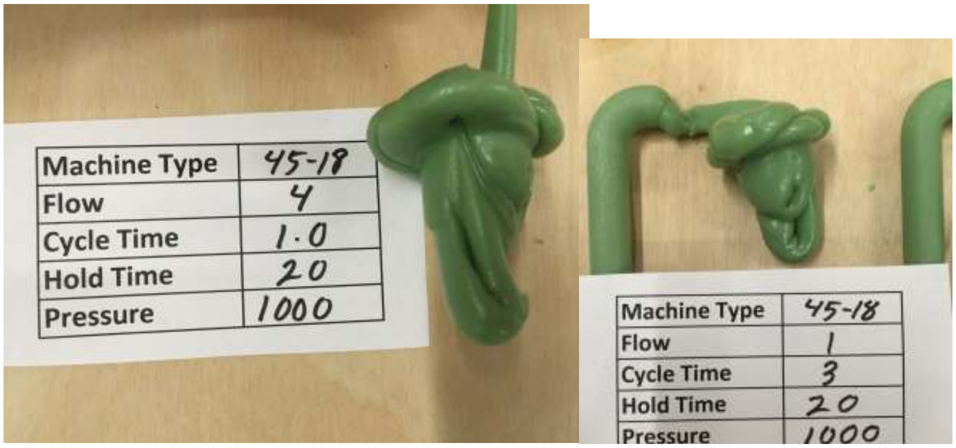
*Figure 6: Sample of Short Shot picture Series*

## Results of Experiment 2

Careful examination of the short shot pictures combined with an understanding of the geometry of the die cavity and specifically the injection runner led to a conclusion. The short shots showed us that the wax entered the die cavity from the injection runner and filled the cavity like a stream of spaghetti. Flowing in this manner the cavity allowed the wax to fold over itself inside the die. This folding allowed air to be entrapped between wax folds. The entrapped air in many instances was completely surrounded by wax. In those instances, the part may prove to be acceptable as no surface defects occurred. In parts were the entrapped air was very near or at the surface of the wax, the part was defective.

The die was examined to see if any possible causes could be determined for this effect. The injection runner with a diameter of 3/8 inch was necked down to ¼ inch just prior to entering the die cavity. The necked down portion of the runner is visible in the die picture figure 1. Figure 7 shows more clearly the resulting pattern from the necked down runner. It was hypothesized that this minor change in the wax's flow path was contributing to the observed condition causing the high defect rate. It is common practice to neck down a runner or gate to allow for easier separation of the runner and/or gate in either wax or metal. That practice may contribute to defective patterns as the wax flow through the necked down portion becomes more turbulent. The decision was made to remove the material in the necked down area allowing the wax a more laminar flow from the runner entering the wax cavity. After the die modification, further testing would be required to observe the results of this change.

*Figure 7: Picture of runner necked down*



| | |
|---|---|
| Machine Type | 45-18 |
| Flow | 4 |
| Cycle Time | 1.0 |
| Hold Time | 20 |
| Pressure | 1000 |

| | |
|---|---|
| Machine Type | 45-18 |
| Flow | 1 |
| Cycle Time | 3 |
| Hold Time | 20 |
| Pressure | 1000 |

*Figure 8: Pictures showing how the wax is folding on itself entrapping air at both high and low flow rates*

## Experiment 3 Plan

The first order of business was to make the needed die modifications. The changes can be seen in figure 9 by looking closely at the point where the runner enters the main die cavity. Compare die figures 1 and 9. The effect of the modification can also be seen by comparing the same area in the pattern, see figure 7 and the last picture in figure 10 for comparison.

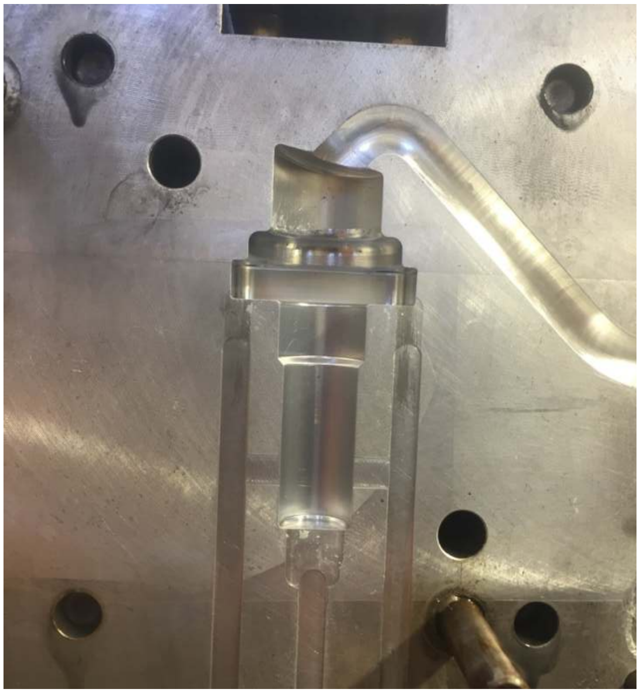


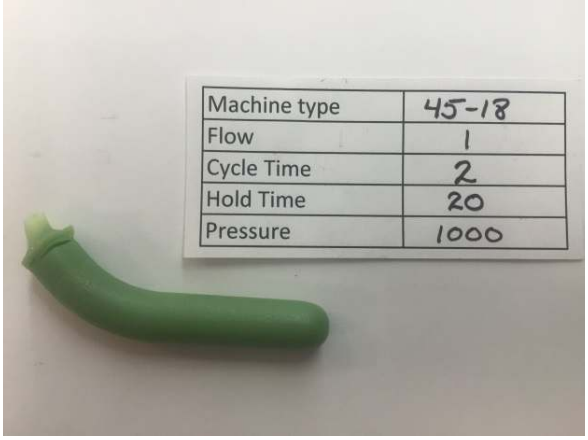
*Figure 9: Modified Die*

The following experiment data was collected and acted upon:

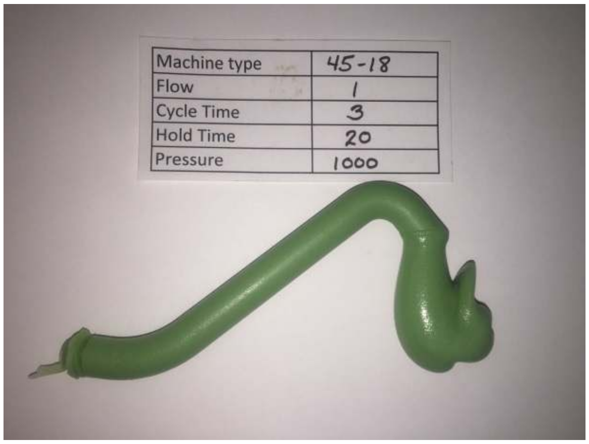
1) Conduct short shots as performed in experiment 2.

2) Conduct 40 injections using the foundry's die and wax. Use both the high and low flow rate recipes (40 injections each flow rate) from the previous optimization process. Capture injection data on the injection graphing unit to help with item 3 below, real-time evaluation of graphing and CSV files for later review.

3) Evaluate each pattern for quality and document the inspection results.



| | |
|---|---|
| Machine type | 45-18 |
| Flow | 1 |
| Cycle Time | 2 |
| Hold Time | 20 |
| Pressure | 1000 |



| | |
|---|---|
| Machine type | 45-18 |
| Flow | 1 |
| Cycle Time | 3 |
| Hold Time | 20 |
| Pressure | 1000 |

| | |
|---|---|
| Machine type | 45-18 |
| Flow | 1 |
| Cycle Time | 4 |
| Hold Time | 20 |
| Pressure | 1000 |

| | |
|---|---|
| Machine type | 45-18 |
| Flow | 1 |
| Cycle Time | 5 |
| Hold Time | 20 |
| Pressure | 1000 |

| | |
|---|---|
| Machine type | 45-18 |
| Flow | 1 |
| Cycle Time | 6 |
| Hold Time | 20 |
| Pressure | 1000 |

*Figure 10: Sample of Short Shot picture Series Post Die Modification*

## Results of Experiment 3

The success of this experiment was evident immediately. The short shots no longer had evidence of wax folding over itself in the die cavity. As a result, entrapped air was eliminated or reduced to a level not detectable. In step two of the experiment number 3, a 40-part injection run was completed with no defective parts found. We observed consistently high quality parts being produced, thereby allowing the die to run in a fully automatic mode. With a 0% defect rate, it was decided to make an extended run. An additional 60 parts were made and one part did show a minor defect, which was repairable with minor rework, however we noted it as a defect giving us a 1% defect rate. The experiment was again run with both the low and high flow settings previously selected and the results were the same 1% defect rate.

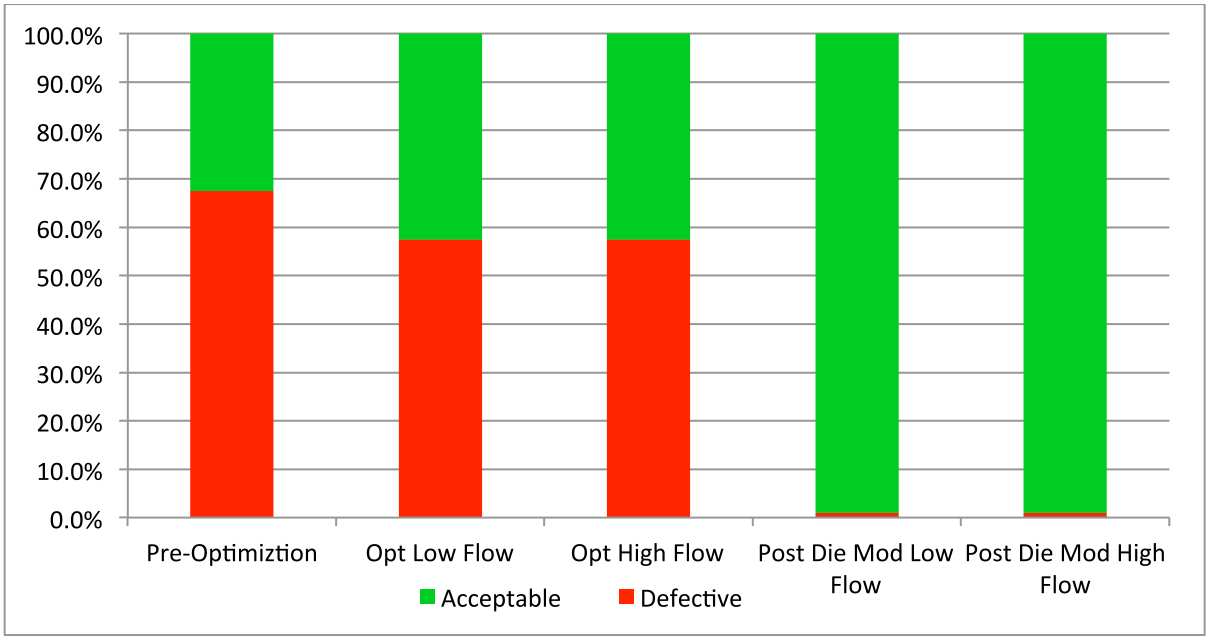


*Figure 11: Defect Rate – Pre-optimization, optimized and post die-modification*

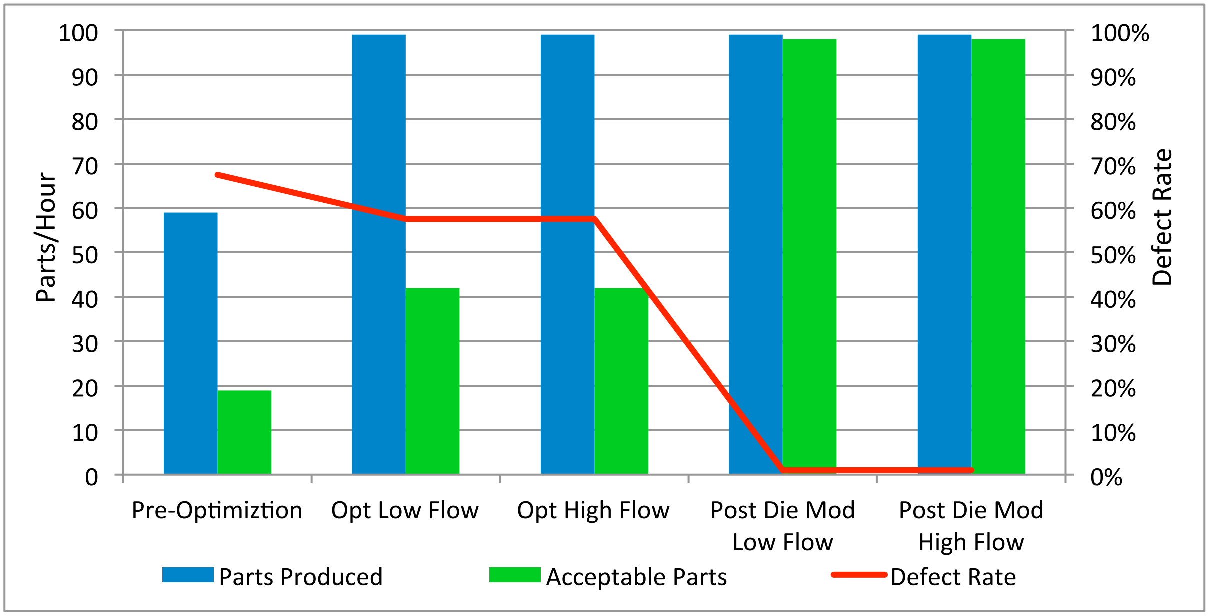


*Figure 12:Parts produced per hour Pre-optimization and optimized*

Overall defect rate was reduced from 67.5% (pre-optimization) down to 1% with the optimized recipe run on the die after modification. This represents a 440% improvement (or otherwise stated a 98.52% decrease) in defect rate. This also resulted in a significant improvement in cycle time per batch of parts.  Previous production capability netted 19 acceptable parts per hour prior to optimization.  This improved to 42 parts per hour with optimization. After the die modification, this was further improved to 98 parts per hour. This is a total improvement of 516% in acceptable parts per hour.  The process changes and die modification combined achieved a more than 5 times throughput gain on this machine with this part.  Additionally, although operator time was not considered a large factor, we have reduced operator time by more than 2/3 as the confidence in the capability in our new set up increased and inspection time was eliminated.

## Conclusions

Wax flow into a die may cause turbulence.  That turbulence may trap air as the wax entraps air inside folds of wax within the cavity.  This entrapped air is very difficult to eliminate, especially when you cannot “see” what is going on inside the cavity.  Using short shots is a good method to help understand the causes of this defect.  In this case, a very simple die modification solved the flow issue.  One can imagine how this defect would be more prevalent and difficult to detect and correct in multi-cavity dies.  We believe this experiment and capturing data correctly in a similar fashion could produce similar results and open the way to automating multi-cavity tools.  Again, it can be seen that good process control on a statistically capable injection machine is a critical component of high quality wax patterns. Dramatic improvements can be made, which allow labor to be utilized for other projects or in this case an automated machine to be freed up to run another job. The part chosen for this experiment was running on a fully automatic press initially, but required significant inspection and roughly 50% rejection of parts. After the appropriate optimization and die modifications were completed the machine availability more than doubled and inspection time (not formally measured) was eliminated. The number of acceptable parts per hour allowed the project to move on to the next phase.

The final conclusion of our experiment and modifications was that this part statistically capably to run on a fully automatic horizontal press. Our next project will be to automate the assembly of this part. This will be completed and the results presented, if accepted, in a follow on paper planned for release during the ICI's Technical Conference scheduled in October 2016 in Columbus, OH. We hope to see you there!

# References:

*Current Problems In The Wax Room And How They Are Best Overcome*

https://www.mpi-systems.com/white-papers.php#.VpQWA43rtwU

ICI *Atlas of Wax Pattern Defects*

ICI *Process Control Course Documentation*

MPI *Wax Injection Operation and Advanced Operation Training*