Improvements in the Burnout Process for Printed Patterns

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Background

The first printed patterns and the majority available today are made from materials that will not melt out in an autoclave. They are either thermosets (like those from SLA or DLP printers) or thermoplastic materials with melting points above those normally encountered in an autoclave (SLS, or FDM printers).

The solution proposed by printer manufacturers and those companies trying to sell printed patterns was to simply burn out the pattern in the pre-heat furnace prior to pouring. However, foundries soon found out that burnout was not so straightforward.

Preheat furnaces are designed to heat shells prior to pouring, not support combustion. As a result, most preheat furnaces have insufficient oxygen to provide complete combustion of printed patterns. Attempts to burn out patterns typically were far less than successful. Material remaining in the mold resulted in significant defects in the castings.

Foundries attempted to increase the oxygen content in the furnace atmosphere by pumping in plant compressed air. However, shells in preheat are typically positioned upside down resting on the pouring cup which effectively shuts off any potential flow of the pumped in plant air into the shell. Even with a grooved furnace floor, the area available for air to flow into the shell was minimal. Little improvement was shown from that step alone.

Access to furnace air could be increased by setting the pouring cup on a couple bricks separated to allow airflow into the shell. However, the shell is a closed volume and flow into the shells would be minimal.

Several years ago, some foundries tried adding vents to each mold to allow air to flow through the mold. This change greatly improved the combustion of printed patterns. Flames would shoot out of the vents like a blow torch, and air would be drawn in between the bricks and into the pouring cup. Now printed patterns could typically be completely combusted. However, ash remaining in the shell still resulted in ash related defects in the castings.

To remove the ash, foundries found they could cool the shell to room temperature and blow out or rinse out the shell. It also gave them a chance to patch the vents added to provide airflow. Cooling the shell created another problem, however. Most foundries use a fused silica shell system and burning out the patterns at 1800F or above resulted in a great deal of cristobalite being created in the shell. When the shell was cooled, cracking occurred in the cristobalite, weakening the shell and creating potential shell failures when the shell was reheated and poured.

To avoid that risk, foundries typically lowered the preheat temperature to 1500F or less during burnout to avoid cristobalite conversion.

Now the industry had a process for burning out printed patterns that could reliably provide acceptable castings. This is the process used by most foundries who cast printed patterns. However, this process has several disadvantages:

- It requires additional labor to cast the pattern including adding the vents, opening the vents prior to burnout, rinsing the shell, and patching the vents.
- Cooling down the shell, rinsing out the ash and patching vents adds at least a day and often two to the casting process.
- While the oven temperature is lowered to avoid cristobalite conversion, it cannot be used to pre-heat normal production shells. To avoid delaying production while burning out patterns, the burnout is typically moved to a time when the furnace is not needed for normal production. That may add as much as another day to the casting process.

These disadvantages are significant but are tolerable to make prototype castings. Being able to provide prototype castings without the time and cost of wax pattern tooling makes the process well worthwhile for prototype and very low volume production castings. For most foundries, prototype castings are a few shells a week and those can be fairly easily walked through the variations in the casting process.

However, the variations required for a clean burnout make it unpractical for any significant production use. It would be extremely difficult to keep track of which shells use the printed pattern process and which use the molded wax pattern process, especially if printed patterns were 20% or more of total production.

If the investment casting industry is going to be competitive in the emerging market for complex geometries (generative design or topology optimized designs which can't be molded), it will be important to be able to use printed patterns for normal production. Normal production will require a much better burnout process.

Proposed Burnout Process

The major disadvantages of the current burnout procedure detailed above are the result of having to cool the shell to room temperature. The shell must be cooled to remove ash and patch the vents. If it were possible to avoid cooling the shell, there would be no change to the furnace temperature, no disruption of production because the furnace temperature was lowered, and it would save at least a day in the casting process.

To avoid having to cool the shell, we need to be sure that:

a. There will be enough oxygen to completely combust the pattern
b. Any ash will be eliminated from the mold in the burnout process
c. There is no need to patch vents before pouring.

With that in mind, we devised a method that might be able to accomplish all the above requirements. The method consisted of two features:

1. **Air injection into pouring cup** – Rather than trying to increase the oxygen content in the furnace atmosphere, air injected directly into the pouring cup will force air with the necessary oxygen directly to the molds where it is needed for

combustion. This forced airflow will hopefully carry out any ash produced during combustion.

2. **Venting Change** - the venting system is changed to one that goes back to the pouring cup as shown in Figure 1. This venting style is commonly used to ensure that no air is trapped in the mold preventing a complete fill. The advantage of this type of venting is that it does not need to be patched prior to pouring.

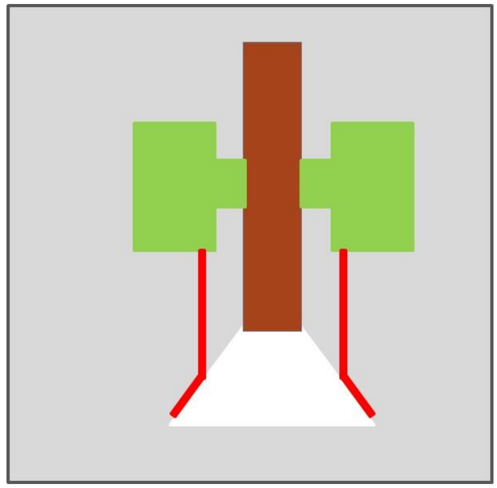

Figure 1, Venting to the underside of the pouring cup.

Testing the Proposed Process

To test our theory, we ran a test of the proposed burnout process in the foundry. Specific tasks included:

1. **Design and build a test fixture** – A test fixture was designed to direct the air stream into the pouring cup. An image of the fixture design is shown in Figure 2. It is designed to allow two shells to be burned out at a time. It was important to introduce some turbulence into the airstream to help flush any ash out of the mold. In addition, we wanted to make sure that any material dropping down from the sprue would not clog the air outlet. Consequently, the air outlet is

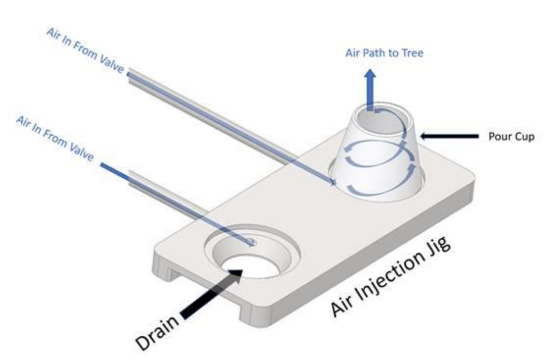

Figure 2, Fixture Design

Figure 3. Completed Fixture

recessed and tangentially to the pouring cup to induce a circular flow. Figure 3 shows the completed fixture. Stainless tubing extended outside the furnace and was connected to air pressure regulators fed with plant compressed air. The fixture was placed in the preheat oven and allowed to come to temperature.

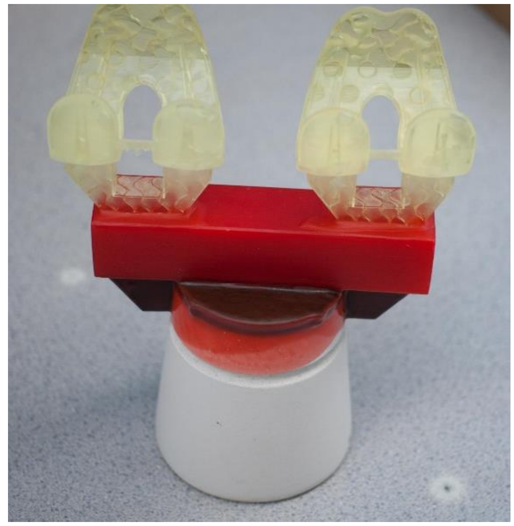

Figure 4. Completed assembly

2. **Select a test pattern** – It was important not to use a test pattern that was too easy nor too difficult to burn out. We also wanted a realistic investment cast component that was not too 2large. We chose an artificial knee geometry. The geometry is relatively complex and has some small columns that will be a challenge to burn out cleanly.

3. **Create Test Shells** – Intrepid Automation created 16 test patterns plus extras for spares. Those were sent to Fenico to assemble and shell. When the shells were complete, the test could begin. A completed assembly is shown in Figure 4. Vents were not added due to a miscommunication, but we went ahead with the test since the shells were all completed.

4. **Burnout Test** – We weren't sure what air flow would be required to both provide enough oxygen for combustion and to carry out any ash created, so we burned out four pairs of shells, each at a different regulator pressure. The pressures used were 0, 5,10 and 20 psi. For each test:
   a. A pair of shells were placed on the fixture in an 1800F oven as shown in Figure 5.
   b. The regulator was adjusted to the desired pressure.
   c. The shells remained in the furnace with airflow for 30 minutes.

d. One shell was removed from the furnace and immediately poured as shown in Figure 6.

e. The remaining shell was removed from the furnace and allowed to cool.

Figure 5. Shells placed on the fixture in the oven.

5. **Identification** – The empty shell was marked with the air pressure used. The poured shell was allowed to cool, the shell was removed and the casting blasted. The casting was marked with the pressure used.

6. **Evaluation of the empty shell** – The shell was cut apart to see if there was any evidence of incomplete combustion. Previous testing had shown a great deal of soot in the shell when there was incomplete combustion. We did not see soot in the Fenico testing.

7. **Evaluation of the casting** – the casting was inspected for surface defects indicating either incomplete combustion or excessive ash.

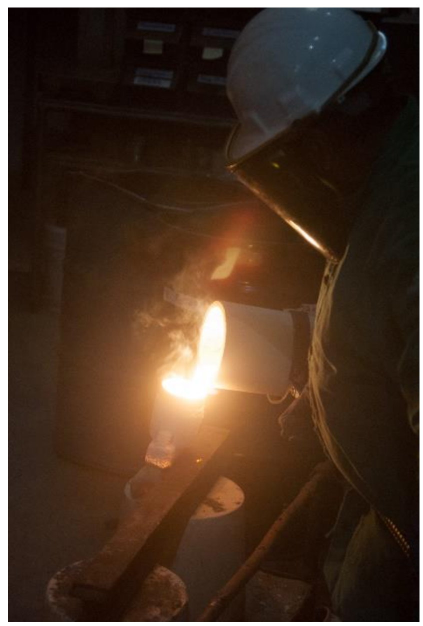

Figure 6. Pouring the mold.

Results

1. 0 PSI (no airflow)

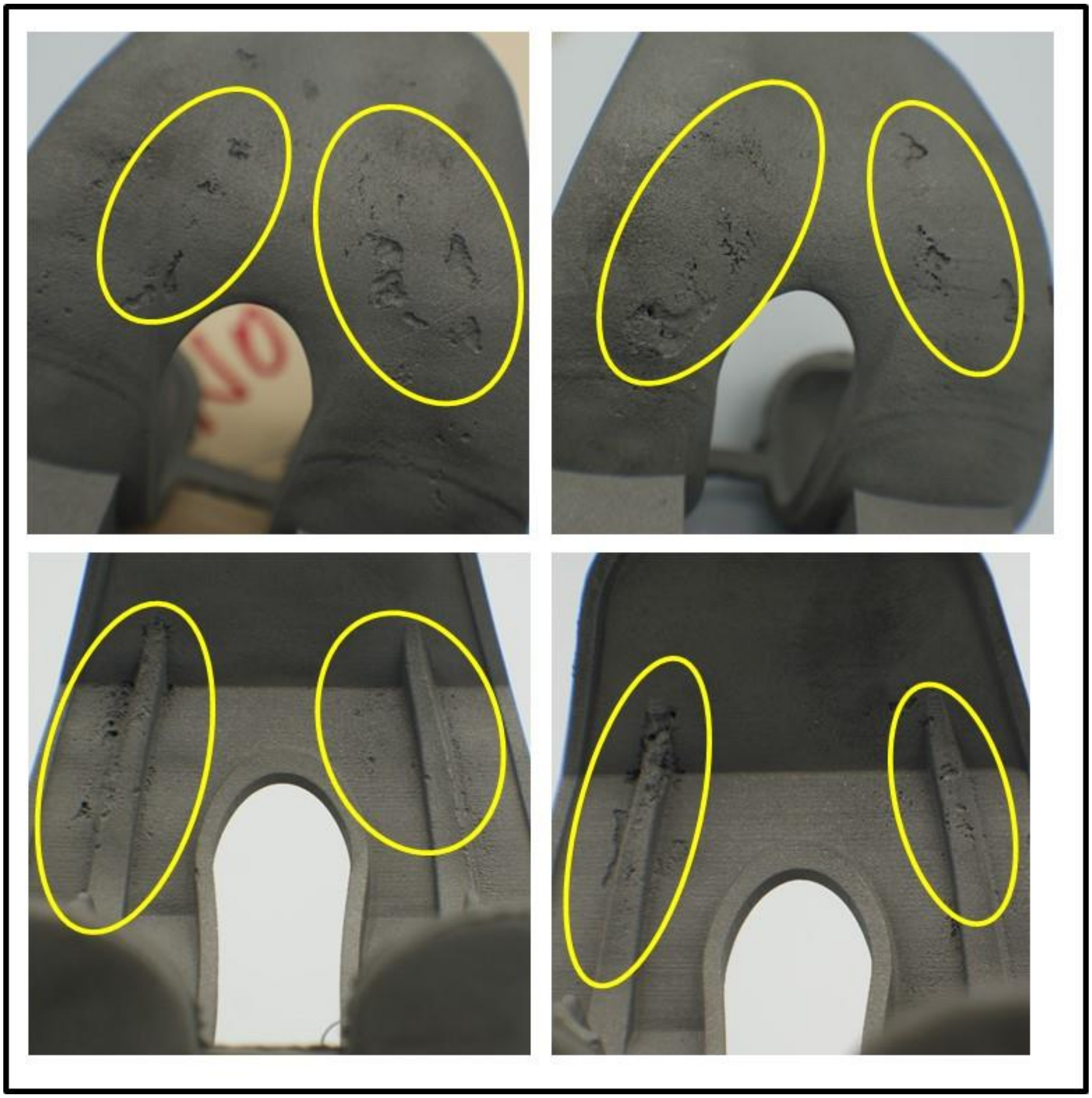

Figure 7. Castings with no airflow.

Clearly there are numerous defects in the castings that would render these unacceptable.

2. 5 PSI

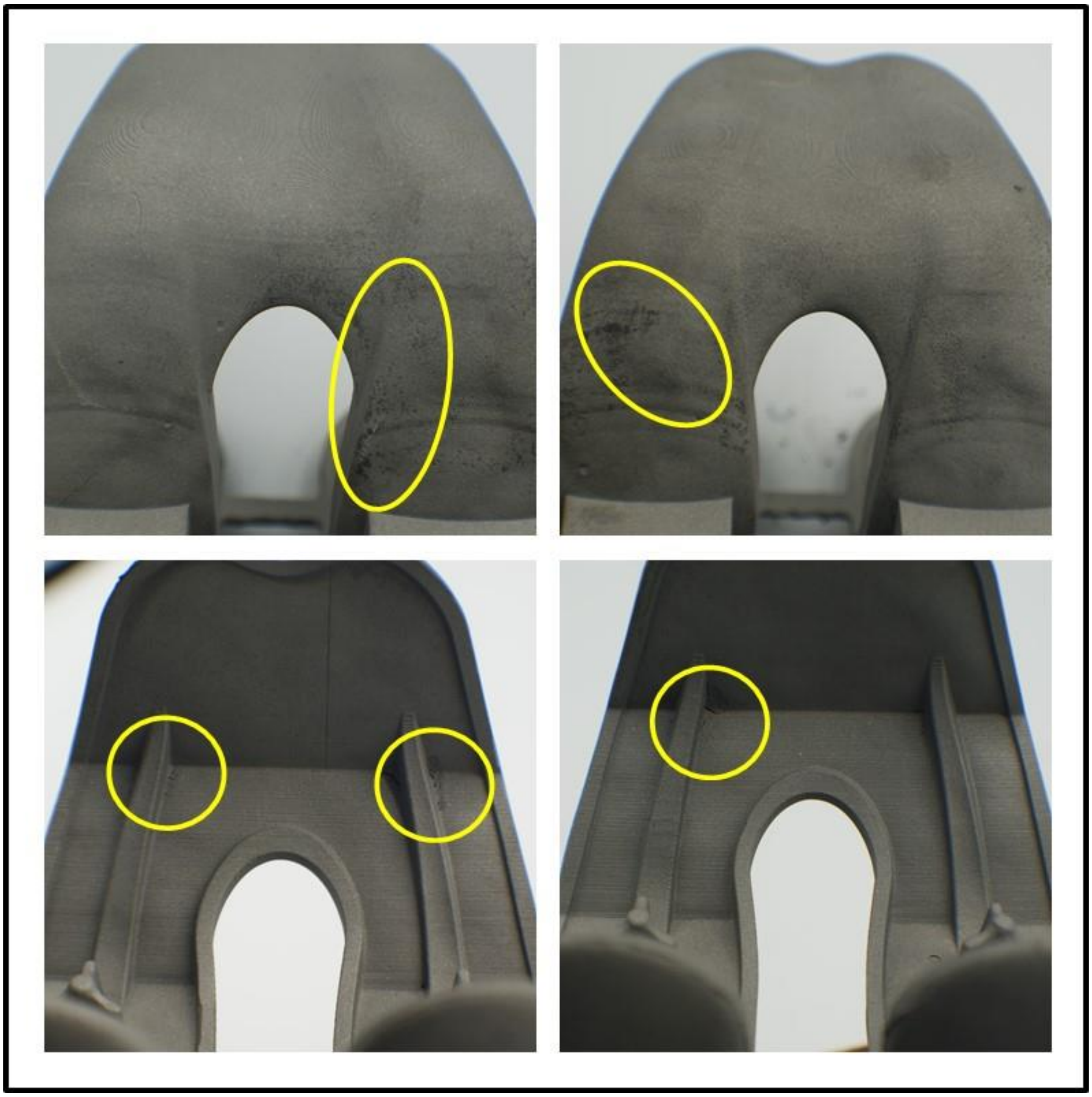

Figure 8, Castings with 5 psi pressure airflow.

Even at this low airflow, there is a significant reduction in the number of defects observed. These castings would require repair and could be marginally acceptable depending on the application.

3. 10 PSI

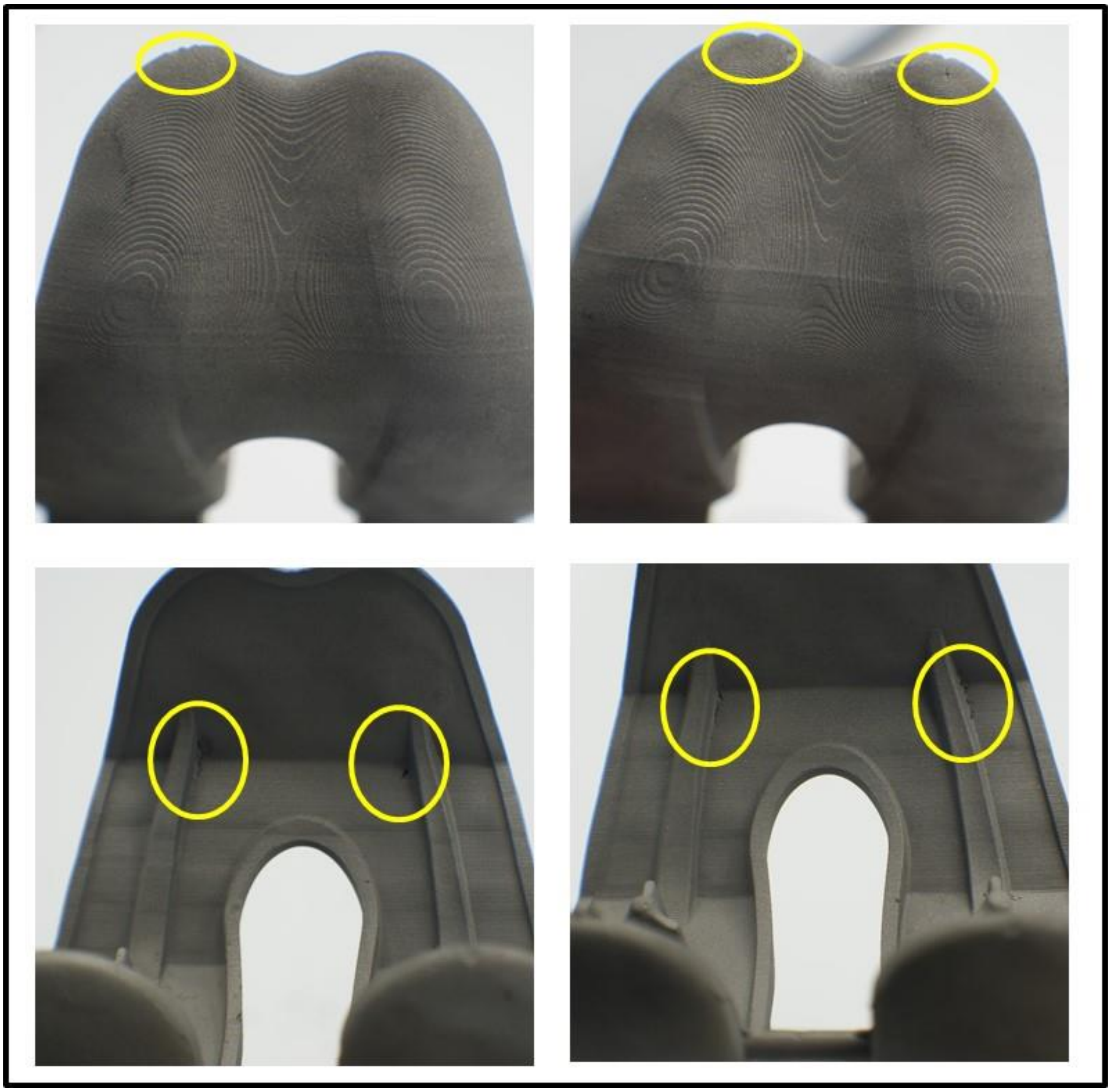

Figure 9. Castings at 10 psi airflow.

There is improvement from the 5 psi. All defects here are relatively minor and depending on the application, might be acceptable.

4. 20 PSI

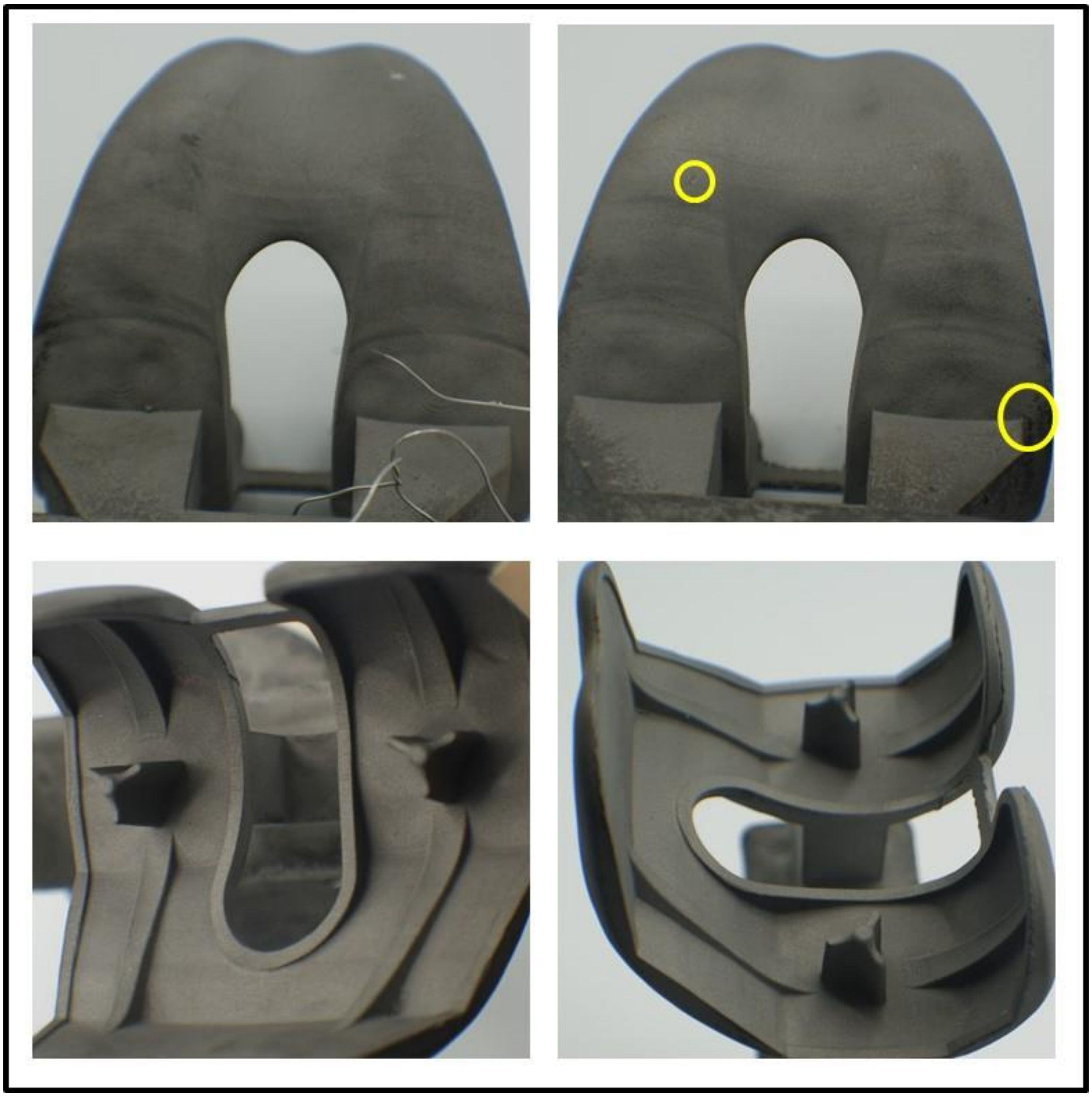

Figure 10. Castings at 20 psi airflow.

It was difficult to find any defects on these castings. They would be acceptable for most applications.

Figure 11 summarizes the results below.

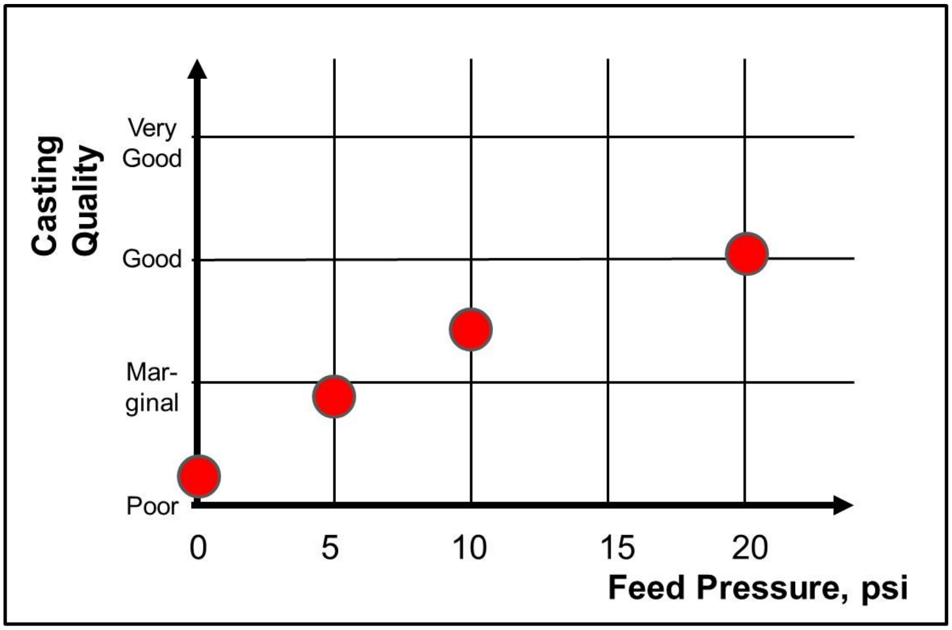

Figure 11, Subjective casting quality vs. feed pressure.

Conclusions

1. At least for this printing process, pattern geometry, resin, and assembly configuration, it is possible to obtain good castings without cooling the shell to remove ash and patch vents.

2. This process saves at least a day in the casting process, avoids production disruptions due to furnace temperature changes and reduces labor required to cast printed patterns.

3. These results show promise for extending the process to other printing processes, pattern materials, and pattern geometries.

4. Except for positioning the shell on the fixture during preheat, the same process can be used to cast these patterns as is used for molded wax patterns, making it much easier to use printed patterns for production runs.

Recommendations

1. Fenico recommended increasing the burnout time to at least 1 hour. That may help to get more complete combustion and reduce ash even more. Since preheat times are generally longer, that will not be an issue in practice.

2. There is some concern that the airflow through the shell is cooling the shell and preventing the shell from reaching the desired preheat temperature. It may be well worthwhile to stop the airflow after a period of time and allowing the shell to come up to furnace temperature. For example, if the normal preheat cycle is two hours, the air could be turned on for the first hour, and then stopped. The remaining hour would bring the shell to desired temperature.

Future Work

While these results are only for this one situation, we believe that we will see similar results for other printing technologies (such as QuickCast, Voxeljet, and a variety of FDM processes), other pattern materials, and a wide range of pattern geometries. However, that is yet to be proven. We will be doing testing to evaluate the process for other situations and will especially be looking at venting configurations, airflow requirements and burnout times.

Based on the results obtained here, we have filed a patent application on the process.