Using Additive Manufacturing to produce Rapid Prototypes through Investment Castings

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It's a problem every buyer dreads - engineering or production needs a single piece, or maybe just a few, of a part that has not been tooled, tested, or approved for production. They need it in a few weeks, the budget does not allow for large tooling expenditures, and waiting months for tooling to be built, samples produced and final approval is not an option. Until recently, there was no solution that would meet everyone's needs - but thanks to recent developments in additive manufacturing, and collaboration with investment casting foundries, help is on it's way. Tech Cast would like to present the following cast study as a perfect example of how you can use this exciting fusion of new and older technology today.

Finding the optimum design for pump impellers is critical to making the most efficient, powerful and effective pumps no matter what the application or the market. However traditionally it has been difficult to design and accurately predict how the actual, physical part will perform with so many complex components playing a role. In the past this was accomplished by building a tool, making samples, testing it, and then either making expensive alterations to the existing tool or building a whole new die - all at considerable time and cost. All too often this has resulted in an incomplete development process, with the customer choosing a "good enough" design rather than an "optimized" design.

Figure 1.
Pattern created through Additive Manufacturing –in this cast through stereolithography

However, in this case Tech Cast, worked with 3D Systems to produce a pattern **(See Figure 1)** via stereolithography, that would replace the traditional wax pattern used in investment casting. Patterns produced through additive manufacturing, introduced over the past several years, provide increased design versatility without physical constraints of conventional tooling. Because these patterns are created using an additive manufacturing technology, (a process that requires no tooling), this makes it possible to have a prototype pattern created at a fraction of the cost and time required for tooling. Creating patterns using additive manufacturing, enables customers to evaluate several design alternatives inexpensively, and simultaneously, to quickly develop a better performing impeller.

STUDY OBJECTIVES

This case study had several objectives:

- Determine the quality of castings created with SLA (stereolithography) patterns relative to those created with wax patterns. Included in the quality evaluation will be:
  - Dimensional accuracy
  - Surface roughness
  - Surface quality
- Determine the relative total cost to create the first casting.
- Determine the time required to create the first casting with each method.

TEST GEOMETRY

In this case, a double suction impeller roughly 16 inches in diameter was chosen, pictured in Figure 2 as the test geometry. The conventional wax injection tooling for this design cost $40,000 and had a lead time of eight to 10 weeks.

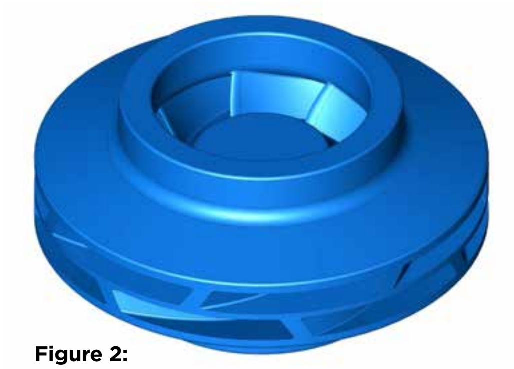

Figure 2:
Test Geometry

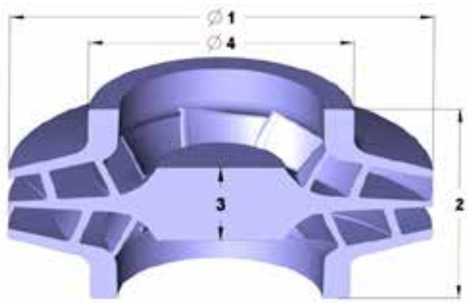

Figure 3:
Measurement Locations

Figure 4:
Casting from Additive Manufacturing/SLA Pattern

TEST & CASTING PROCEDURE

Tech Cast processed the SLA pattern using the standard investment casting process. This involves dipping the pattern into a resin slurry, and building up enough layers to create a shell that is durable. The shell is then heated to 1500° F, causing the SLA pattern to burn and leave a void in the shell. The shell is then washed out to ensure no debris remains, and the molten steel is then poured into the shell mold. Once the metal has cooled, the shell is broken up and the actual part is ready to be inspected. Tech Cast documented labor hours at each step of the process and compared the casting results between SLA patterns and conventional wax patterns.

RESULTS / Dimensional Accuracy

Tech Cast measured critical dimensions on both the patterns and their respective castings. Figure 3 shows the location of the four dimensions measured on each pattern or casting. Table 1 shows measurements of the patterns which are scaled to compensate for shrinkage. The accuracy of the additive manufactured pattern was comparable to the wax pattern. The largest deviation from an individual measurement for the SLA pattern was .004". All deviations were less than one tenth of a percent compared to the nominal value and insignificant when compared to the tolerances of the casting requirements. **This is significantly better than can be produced in either green sand or no bake methods.**

Table 1:
Additive Manufacturing /SLA Pattern Comparison

Dimension ID	Target	Actual	Deviation	%Deviation
1	15.955	15.959	0.004	0.03%
2	7.782	7.779	-0.003	-0.04%
3	3.030	3.032	0.002	0.07%
4	9.745	9.747	0.002	0.02%
Average Absolute Percent Deviation				**0.04%**

Dimensional inspection of the castings is shown in Table 2 below. Both castings showed similar deviations to the intended casting target with an average dimensional error less than one percent. From a dimensional accuracy viewpoint, the SLA pattern demonstrated the capability of producing a predictable, precise casting.

Table 2:
Casting Comparison

Dimension ID	Casting Target	Casting from wax pattern			Casting from SLA pattern		
		Actual	Deviation	%Deviation	Actual	Deviation	%Deviation
1	15.75	15.880	0.130	0.83%	15.728	-0.022	-0.14%
2	7.63	7.560	-0.070	-0.92%	7.615	-0.015	-0.20%
3	2.93	2.933	0.003	0.10%	2.949	0.019	0.65%
4	9.62	9.648	0.028	0.29%	9.581	-0.039	-0.41%
Average Absolute Percent Deviation				**0.53%**			**0.35%**

Table 3:
Surface Finish Comparison

Pattern pattern	Surface Roughness (μin Ra)
Wax	122
SLA	159

Surface Roughness

Surface roughness was measured on each of the castings as shown in the table below. The casting from the additive manufactured pattern had a rougher surface but remained within limits for the casting application, and well below the typical surface roughness of a no bake casting (150-600 µin Ra) or green sand (250-900 iµ Ra)

Surface Quality

Surface quality refers to the absence of surface imperfections that detract from the appearance and functional performance of the component and may require repair. Such imperfections can include negatives to the surface such as pitting or cracks, or positives to the surface that could result from shell imperfections. The casting made from the SLA pattern exhibited an increase in negative areas on the casting, however, the severity of the surface defects did not impact casting performance.

COMPARING THE PROCESS

As outlined earlier, the basic casting process remains the same if the foundry is using a traditional wax pattern compared to a 3D printed pattern - however the cost and time savings are realized through additive manufacturing not requiring tooling to be built.
A comparison of the respective timelines is shown below.

Table 4:
Process Comparison

Step	Description	Wax Pattern	SLA
CAD Modeling	Incorporate pattern shrink, solidification modeling and gating into the casting design	0-1 Week	
Pattern	Obtain soluble core and pattern tooling or SLA pattern	7-9 weeks	1-2 weeks
Foundry Processing	Process the pattern through the foundry and clean the casting	1 -2 weeks	
Time to First Casting	Time from receipt of order to shipment of first casting (Casting complexity and value added services may affect this time)	9-12 weeks	2-5 weeks
Cash Expenditure	Purchases required to obtain first casting	$40,000	$3,150

CONCLUSIONS

- **Casting Quality**
  While not quite as good as a casting made from a wax pattern, the quality of a casting made from an additive manufactured/SLA pattern is good enough for all but the most demanding applications.

- **Cost of the First Casting**
  The foundry must invest $40,000 into tooling before obtaining the first casting when using wax patterns. If they choose to use SLA patterns, they need only invest $3,150, less than 10% of that required for molded wax patterns.

- **Labor Content of Castings**
  Casting a SLA pattern requires similar labor compared to a wax pattern.

- **Time to First Casting**
  Additive manufactured patterns allows the foundry to deliver the first casting 6-8 weeks faster than wax patterns.

- **Machining**
  Due to the combination of improved surface finish and the processes ability to hold tighter tolerance, in many cases parts can be produced without the need for additional machining operations, which may be required if using traditional green sand or no bake casting methods.

- **Applications**
  - **Direct manufacturing**
    SLA patterns reduce the total costs of finished casting for limited runs or low volumes without significant sacrifice to casting quality.
  - **Repair Parts**
    No investment of injection tooling for one-off repair or legacy items.
  - **Concurrent Designs**
    An additive manufactured pattern ordered simultaneous with wax tooling allows the foundry to prove out processing during tool construction.
  - **Research & Development**
    Multiple variations may be tested at the same time without incurring tool alteration costs.

As this technology continues to be developed, we can expect to see a further reduction in lead times, equipment costs, raw material pricing, and improved efficiencies as the foundry becomes more familiar with the process. Companies such as Tech Cast are there to help our customers not only just produce parts, but to educate design and purchasing teams on these new technologies and how they can be applied to each customers unique need.

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