65th Annual ICI Technical Conference, Kansas City MO, October 21-24, 2018

3D Printed Sand Molds – An Opportunity for Investment Casters

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Abstract

The use of 3D printed sand molds and cores for the production of low production volume sand castings is both a threat and a new business opportunity for investment casters. This will be discussed in the context of other 3D printing technology pathways for producing metal components. 3D printed sand mold castings can also be produced by investment casters without the need for pattern tooling or sand molding systems. The melting capabilities of most investment casting operations are well suited to the casting size and production quantities for 3D printed sand molds. The wide availability of purchased printed sand molds produced by service bureaus, allows investment casters to quickly develop printed mold sand casting services and markets with small initial equipment investments.

Introduction

3D printing technologies to directly produce complex parts without physical tooling have been under development for more than 25 years. The recent explosion of interest in this family of technologies has moved 3D printing from an interesting curiosity to an accessible processing method for specific, unique part designs. However, these processes are still very limited in their ability to cost effectively produce metal components directly. Many challenges still remain before component shapes that can be produced by other traditional methods can be cost effectively produced by direct 3D printing technologies.

The broad adoption of 3D printing technologies will depend not only on continuing process development to improve 3D printed part quality and reduce component cost, but also on the development of business strategies and strategic alliances between technology partners to integrate component designs with 3D printing constraints.

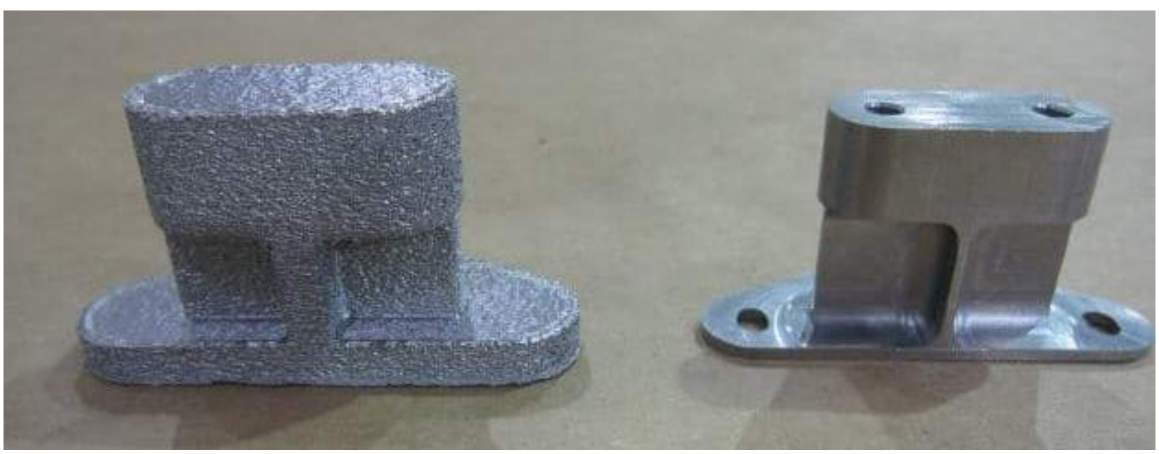
3D Printing Technology Pathways for Metal Parts

Direct 3D printing technologies for the direct production of metal parts are still in their infancy compared to the 3D printing of plastic or ceramic parts. Much of the design community's future vision for 3D printing is based on the current capabilities of low-cost plastic printers to produce complex, low dimensional tolerance artistic components. The direct production of high quality, net-shape 3D printed metal parts is for the most part, still a future dream, but not a current reality. At present, direct 3D printed metal parts have variable quality and produce near-net-shape features that require significant secondary processing to achieve desired performance and dimensional tolerance specifications.

However, direct 3D printing of metal parts for critical engineering applications is not the only pathway to exploit the advantages that 3D tooling-less manufacturing of complex metal components can offer. The investment casting industry has already fully embraced hybrid investment casting strategies that use 3D printed wax and plastic patterns rather than hard tooling to produce investment castings. In a similar way, sand casters are embracing direct 3D printing of sand molds and cores as a competitive way to produce complex metal parts directly without the need for hard tooling.

Direct Printed Metal Parts	
Adoption Incentives -shape complexity -lead time reduction	**Adoption Barriers** -limited part sizes; long build times -severe stair-stepping; poor tolerances -secondary processing necessary -limited alloy choices
Trends -continuing development efforts by the aerospace, DOD and university communities -very limited adoption in the near term -design restrictions and processing guidelines have not yet been established	

Figure 1 shows a direct laser-printed titanium alloy component in the as-built and final machined conditions. Although build geometry and surface characteristics depend on the specific direct metal 3D printing method used; in general, the dimensional tolerances of direct-printed metal parts do not come close the those of conventional investment cast components. Direct metal printing offers great flexibility in the shapes that can be produced in theory; however, in practice at the present time feature detail and tolerances are quite limited. [1,2]



a) b)

Figure 1: 3D direct metal printed titanium alloy component. a) build geometry and surface finish b) final machined component. [12]

In addition, complex component designs must include considerations for integral printed support structures that are necessary to avoid significant part distortion during printing or subsequent secondary processing. These support considerations must be addressed during part design and apply significant geometric constraint to direct metal printed ‘buildable’ part designs.

Current generation direct metal printers are expensive, have limited build envelopes and long build times. Most of the current efforts in direct metal 3D printed are still in the research and early development stages. [3]

Printed Wax/Plastic Patterns for Investment Castings	
Adoption Incentives	**Adoption Barriers**
-reduced first article lead time -reduced cost for low volume parts -more shape complexity possible	-rougher surfaces with some stair-stepping visible on parts -dimensional adjustments when going from printed waxes to hard tooling
Trends -purchased 3D printed patterns are used throughout the investment casting industry -surface texture and dimensional tolerance improvements continue	

The use of 3D printed wax patterns or honeycomb plastic patterns for short-run investment casting has been widely adopted by the investment casting industry during the past 10 years. [4,5] Figure 2 shows the details of surface details for printed wax and honeycomb plastic patterns. In all but a few cases, investment casters purchase printed pattern and cores from service bureaus rather than printing them in-house. For some investment casters, the annual cost of 3D printed patterns now approaches the annual cost of conventional hard tooling.

Similarly, the development and adoption of direct printing techniques for ceramic cores has opened up new opportunities for complex investment casting internal passageways that promise to continue to expand high-end markets for investment castings. [6]

Figure 2: Surface characteristics of investment castings using a printed pattern [7]

Investment casting using 3D printed wax/plastic patterns has been widely adopted by most investment casters. Aside for some challenging burn-out considerations for plastic patterns, there are no major technical hurdles remaining for adoption of these techniques. Market trends suggest continuing surface quality improvements and reduced purchase costs for both printed wax/plastic pattern and for printed ceramic cores. [4]

Printed Plastic Patterns for Sand Casting	
Adoption Incentives -short run printed tooling can be created directly -reduced pattern lead time	**Adoption Barriers** -shape complexity is limited by cope and drag molding methods
Trends This process has made few inroads due to the fact the conventional CNC machining of conventional patterns and coreboxes is very cost competitive	

3D printing techniques can also be used by conventional sand foundries to directly print limited durability, permanent plastic pattern and coreboxes for conventional sand casting. Early process development efforts focused on the promised shorter pattern lead times expected for printed plastic patterns. However, it was soon realized that the geometric constraints of reusable patterns for cope and drag molding limited the potential geometric advantages that 3D pattern printed patterns could offer. Lead time reduction trials demonstrated that the potential lead time benefits for 3D printed pattern production were slight and were not cost justified when compared to convention CNC methods for producing hard tooling and core boxes. The large size of pattern and core boxes also meant that printed plastic pattern distortion was sometimes difficult to overcome. Commercial development efforts in this area have slowed and almost stopped with the exception of specialized layering/machining techniques for rapidly producing large patterns. [8]

Printed Sand Molds/Cores	
Adoption Incentives -More complex geometries can be cast -Large shapes can be produced using conventional alloys - Can be used for cores and/or molds	**Adoption Barriers** -the high cost of large bed sand printing machines
Trends -rapidly growing interest in sand and core printing for both prototypes and for complex production components. Printed cores used in conventional sand molds is growing at a faster rate than the use of printed molds with printed sand cores	

3D printing techniques can also be used to directly print sand molds and cores used for direct metal pouring. [9-14] Similar to other methods, this pathway does not require the use of a permanent pattern or core boxes to produce complex internal and external geometries for castings. Various conventional foundry resins are printed onto flat sand beds to produce bonded sand molds and cores one layer at a time, Figure 3. 3D sand printers with very large printing beds allow large sand molds and cores to be produced. Typically, the sands used for printing are coarser than metal powder and wax/plastic droplet used in other 3D printing systems, but the build times are much faster.

In particular the ability to 3D print complex one-piece sand cores, to replace multiple core assemblies produced in conventional core boxes, has rapidly made in-roads, Figure 4. The cost of printed cores is significantly less that the cost of printed molds because the bounding box for cores is significantly less than that of the surrounding mold. In addition, complex core geometries can be 3D printed that are not possible using conventional tooling. This offers a great opportunity for many classes of complex internal geometry parts including impellors and pumps.

At the present time, most sand foundries purchase printed molds and cores from vendors. However, lower cost sand printing machines have been purchased by some small jobbing foundries to add printed sand molds and cores to their basic molding capabilities.

Figure 3 Example of a large bed sand printer used to make both molds and cores. [12]

a) example of a complex printed sand core coated with a refractory wash. [13]

b) typical surface finish of a steel casting made from a printed sand mold [15]

Figure 4 Printed sand molds and cores a) example of a complex printed sand core coated with a refractory wash. b) typical surface finish of a steel casting made from a printed sand mold.

3D Printing Technologies for Investment Casters -- Pathways and Partners

The technical pathway from initial casting design to final cast component is different for each type of printing system used for metal components.

The development, adaption and final adoption of new 3D printing processes and systems for complex metal parts is well underway. However, the important question to address is the final scale of adoption. Will a given metal 3D printing pathway be developed, adapted and then discarded? …..or will it result in limited industry adoption….or will it result in broad industry adoption? At this point in time the development and adoption trajectory can be evaluated to give some insight into the future of 3D printing processes and systems.

It is also important to track the emerging business models and technology partners that a part of the pathway from initial component design, through casting system design, through pattern and mold production, through casting operations, and through final finishing and inspection. It is not uncommon for separate casting engineering service vendors, printing vendors, as well as casting and finishing vendors to be part of the pathway from component design to final 3D printed metal part. The more supply chain partners that are part of the system, the more difficult is the component development pathway and the opportunity for profitable sustainability.

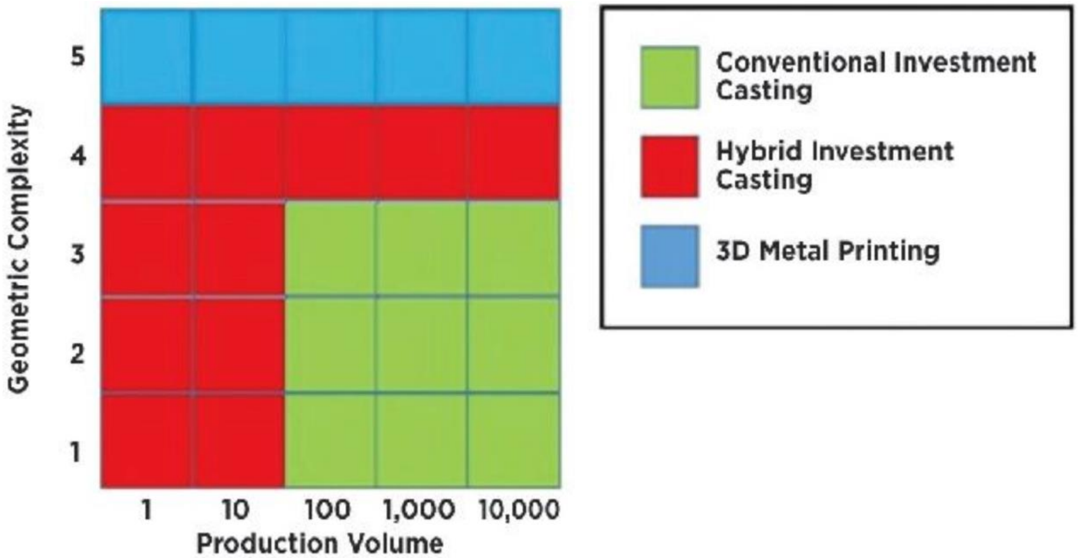
Direct 3D Metal Printing vs. Investment Casting vs. 3D Printed Pattern Investment Casting

The high cost and poor quality of direct 3D printed metal parts will continue to be a barrier to broad adoption. The promises of low cost, complex, net shape engineering components cannot yet be readily achieved. Part designers with visions of 'infinite' component shape flexibility do not have adequate design constrain guidelines to guide their design thinking. Metal printing systems are slow and costly, the dimensional and metallurgical quality of the direct printed parts is often poor. Precise final net-shape geometries often require secondary operations and required metallurgical quality may require post-build HIPing to achieve desired properties and soundness. Appropriate industry-wide specifications and quality control standards for direct 3D printed parts are not available.

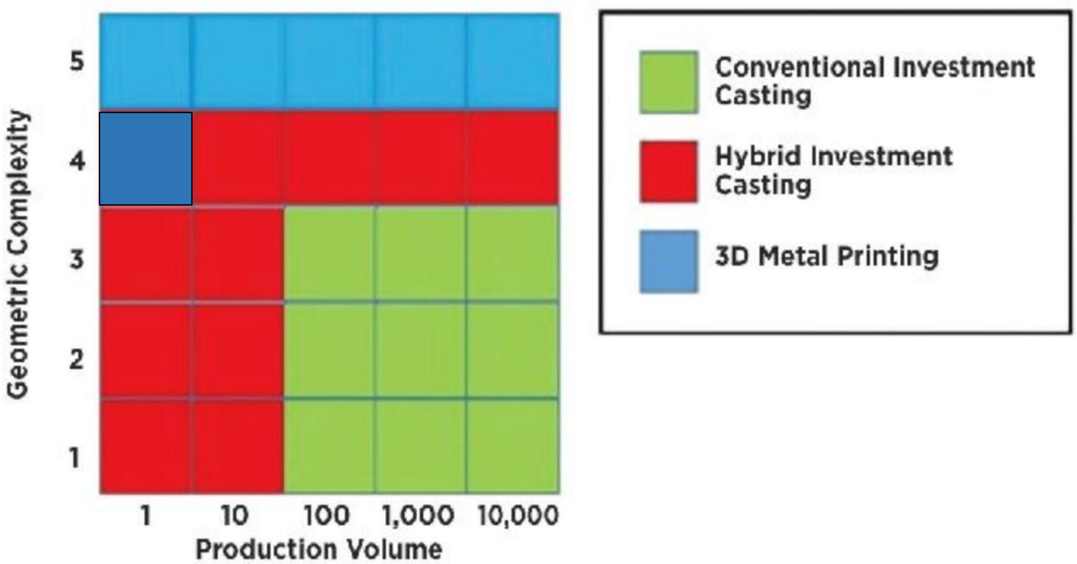
The use of 3D printed wax/plastic pattern technologies for investment casters in a very short period of time has gone from the development stage to broad industry adoption. For some investment casters the annual cost of purchased 3D printed wax/plastic printed patterns exceeds the annual cost of purchased hard tooling. These techniques can result in significant reductions in first article casting lead time for which the investment casting customer is willing to pay a premium price. The additional geometric complexity that printed pattern and cores make possible give customers the design flexibility that investment casters can readily manage. Most printed patterns are currently produced by third party vendors who are content to sell patterns and have no desire to compete directly in the investment casting business.

A recent analysis by Mueller has examined the impact that 3D printed metal parts will have on investment casting [3]. This study has focused on the possible impact of direct 3D printed metal components being substituted for conventional investment castings and 'hybrid investment castings' using 3D printed wax patterns.

Mueller models the expected cost impact of casting complexity, casting production volume and expected production costs on the selection of conventional investment casting, hybrid investment casting or direct 3D metal printing as the preferred production method. Figure 5 shows the expected least cost production method for 8-inch components based on current production costs as well as expected production costs if the cost of direct 3D printed parts drops to 25% of current production costs.



a) based on current production costs



b) based on 25% of current production costs

Figure 5 The least expensive method of manufacture for 8 in. (200 mm) components a) based on current production costs b) based on 3D metal printing costs that are 25% of current costs [3]

Mueller's analysis clearly shows that direct 3D metal printing is not expected to be a significant threat to investment casting markets in the coming years. There are other technical reasons that support this conclusion that are not directly included in Mueller's study. However, another 3D printing technology pathway, printed sand mold and core technologies, can be expected to have an impact on investment casters.

3D Mold/Core Sand Printing for Investment Casters

During the past 5 years there has been rapidly growing interest in the use of 3D printed molds and cores for sand casting. [14] These developments parallel the rapid deployment of 3D printed wax/plastic patterns in the investment casting industry. This parallel is because the deployment of 3D printed sand mold/core technologies offer the same advantages to conventional sand casting methods – reduced lead times for first article castings, additional sand casting design flexibility particularly for internal passageways, and often cost savings.

3D printed sand cores made without corebox hard tooling, can also be effectively coupled with conventional sand casting patterns and methods to produce complex internal passageways in sand castings that were costly or not possible with conventional hard corebox tooling. These new capabilities from 3D printed sand technologies that have been embraced by the foundry industry can be expected to effectively compete with investment casters in certain market segments. The extent of the impact on investment casters cannot be accurately predicted.

But the development of 3D printed sand mold/core technologies can also offer a significant opportunity for investment casters as a ‘molten metal vendor’. Designer’s considering 3D sand printing for new part development are faced with a confusing supply chain of venders that must partner together to go from initial concept design all of the way to delivered metal component. Just as printed wax/plastic vendors must partner with investment casters to deliver a metal casting from a printed pattern, printed sand vendors must partner with a metal caster to provide their metal castings. Printed sand vendors can partner with either sand foundries or investment foundries for the final melting, casting and cleaning steps.

Conventional sand casting requires significant investments in sand and core molding systems to mold and recycle bonded sand. However, investment foundries do not need to operate complex, expensive sand mixing and molding systems to pour ‘sand castings’ in printed sand molds. Investment casters, who typically cast a wide variety of alloys using a wide range of small induction furnaces. can become flexible responsive molten metal vendors. After casting, spent printed sand molds and cores can simply be disposed of or reprocessed by outside vendors. The on-demand molten metal capability cannot be matched by most sand foundries who tend to have larger furnaces and cast fewer alloys.

Summary

The impact of 3D printing technologies on the investment casting industry is a story that has yet to be told. However, part of the story is clear. Direct 3D printed metal technologies are still in their infancy with many major technical and cost hurdles before they can become a commercial success that competes strongly with investment casting. In the near future, the impact of 3D printed sand molds and cores to produce complex metal shapes offers many more opportunities for designers. These printing technologies will allow sand casters to compete with investment casters for certain classes of complex parts and at the same time will allow investment foundries to provide casting services for printed sand components.

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