Using 3D Printing in the Investment Casting Process
Metal 3D printing has opened up a range of new design possibilities for manufacturers looking to reduce weight and piece counts. Technical feasibility isn’t the same as economic feasibility though and 3D printing of metal parts remains expensive.

Incorporating 3D printing in the investment casting process lowers tooling costs and enables realization of more complex designs. It also cuts the time needed to bring a new investment cast part to production. This eBook explains the impact 3D printing is having on one of the oldest processes for manufacturing metal parts. Individual sections address:

- The investment casting process
- Why and when to use investment casting
- Limitations and drawbacks of investment casting
- 3D printing of metals and wax
- Challenges in 3D printing of metals
- How 3D printing can be used in investment casting
- Advantages of 3D printing investment casting patterns
- Limitations of using 3D printed patterns
- When to use 3D printing with investment casting
The Investment Casting Process

In common with other casting processes, investment casting involves pouring molten metal into a cavity the size and shape of the required part. After the metal has solidified the part is released and finished as needed. Where investment casting differs is in how the cavity is formed.

Historically, investment casting starts with a wax replica of the part to be made. A wax channel is then attached through which metal will be delivered. Additional patterns are prepared the same way and then assembled into a “tree” with a central distribution system. This tree is given multiple coats of a ceramic slurry which dries to a hard shell around the pattern. The wax is then melted out in a process investment casting specialist call “burn-out.” This leaves a void for the molten metal to fill.

As the pattern is sacrificed during the casting process each finished part needs a new pattern. Today these patterns are made mostly through injection molding of wax. The preferred materials are those that leave least residue or “ash” behind after burn-out as ash has an adverse effect on part quality.
Why and When to Use Investment Casting

There’s no limit to the metals that can be investment cast. Inconel, stainless steel, and aluminum are just a few examples. As the ceramic slurry conforms closely to the pattern the process is capable of producing intricate forms that need minimal machining. Thin sections and textured surfaces are also feasible. This makes it attractive for high volume production of small to medium-sized parts. Medical devices and aerospace components are frequently investment cast, as are some automotive parts.

Limitations and Drawbacks of Investment Casting

Pattern production strongly influences both process economics and design flexibility. In new production introduction it also extends lead time.

The issue here is with the wax injection molding tools used to form the patterns. Machined from steel, this is expensive and time-consuming to make. Tooling lead times can extend from weeks to months. Once tooling is proven through, the incremental cost of producing additional patterns is very low.
Design flexibility is constrained by the need to release the wax pattern from the mold cavity. There are also limits on placement of inserts or cores for internal voids in the metal part.

**3D Printing of Metals and Wax**

Several technologies are available for 3D printing wax. The first of these, and forerunner of all 3D printing techniques, was stereolithography (SLA). This is where focused light is used to cure a photoreactive wax.

Today desktop printers use the fused deposition modeling (FDM) technique. This is where wax is extruded through a nozzle and the part-built layer-by-layer.
Industrial systems often employ selective laser sintering (SLS). This is where a thin layer of wax powder is deposited on a bed and then selectively fused by laser. A new powder layer is deposited and the laser is rastered over the surface again, the process being repeated until a part has been completed. SLS offers higher speeds and greater accuracy than FDM and can work with a wider range of wax.

Wax 3D printing is used primarily to create prototype parts with the look and feel of production items. However, usage is growing for tooling, both for grippers and guides and in molding and casting.

3D printing of metals is newer and continues to evolve. The most widely used technique is direct metal laser sintering (DMLS). This is similar to SLS although it requires higher laser powder to create the temperatures needed to fuse powder grains. A useful feature of DMSL is that it seldom requires support structures. Instead, the unsintered powder has sufficient rigidity to support overhangs so DMSL is therefore used to create highly complex metal parts with projections and re-entrant features.
Aerospace and motorsport manufacturers are making increased use of metal 3D printing for prototype parts and very low production quantities. For businesses in these industries the technology has two attractions:

- Enables consolidation of multiple parts that otherwise require assembly into a single piece
- Permits extreme weight reduction through an optimization process known as generative design

Generative design is where software is used to explore a wider range of solutions than a human designer could investigate. The result is often organic-looking forms that maximize strength while minimizing the amount of material used. Their major limitation is that frequently they cannot be produced by conventional forming and machining processes, leaving 3D printing the only option.
Challenges in 3D Printing of Metals

Four factors work against 3D printing being used for anything other than high value parts made in low quantities. These are:

- Time needed to “print” a part
- High cost of metal 3D printing technology
- Risk of internal defects
- Limited number of material options

Despite growth in laser power, building a part layer-by-layer remains a slow process. The problem is magnified when thinner layers of powder are deposited, which is done to improve resolution and minimize edge layer effects.

Add to this the high price of the machines used for 3D printing metal and the process becomes extremely costly. This is especially true for parts larger than a few inches in volume, where the bigger bed size machines needed are extremely expensive.
A concern with 3D printed metal parts is the risk of internal defects. This could occur for example if the powder moved or was not deposited correctly prior to sintering. This is why, for demanding or safety-critical applications it’s common to perform 100% inspection by CT. Clearly, this adds significant cost to the printed parts.

The DMLS process requires metal powder with an appropriate grain size distribution. This limits the variety of metals that can be printed to a relatively small number of alloys which are specially formulated for the process.

In summary, while 3D printing of metals is technically feasible, subject to alloy limitations, in only a few niche applications is it cost-effective. However, this need not prevent manufacturers taking advantage of the design flexibility afforded by the process. This is done by combining 3D printing with investment casting.

How 3D Printing Can be Used in Investment Casting

Patterns for investment casting can be 3D printed rather than molded. Taking this approach, it’s possible to produce metal parts with the complexity of 3D printed parts but with the economics and integrity of casting.

The key to performing this successfully is to use a wax with excellent burn-out characteristics. At the same time it must spread and fuse readily for use in SLS machines. Not all wax provide a clean burn-out with minimal residue: 3D printing specialists with investment casting expertise can advise on those that do.
In practice the required pattern is 3D printed before being attached to a tree. From here the usual investment casting process is followed with the tree being coated before burn-out.

**Advantages of 3D Printing Investment Casting Patterns**

The hybrid process described above offers five major improvements over both conventional molded-pattern investment casting and metal 3D printing:

1. Able to create the same complex 3D geometries as metal 3D printing
2. Minimal pattern production lead time compared with injection mold tools that take weeks or months to produce
3. No limitations on type of metal alloy
4. No defects due to missteps in the powder deposition process
5. Casting process creates multiple identical pieces in very little time, which results in much lower piece costs than 3D printing one at a time
Limitations of Using 3D Printed Patterns

3D printing of wax is far slower than injection molding, but mold tools are expensive. The issue here is one of volume. For large quantities injection molding will yield lower piece costs, but with design limitations. For low volumes 3D printing can be more economic. Exact breakeven quantities depend on the size of patterns needed. This dictate both mold tool size and production rate off the molding machine.

In addition, as investment casting does an excellent job of reproducing the surface finish of the pattern, some finishing will almost certainly be needed before tree assembly. In contrast, an injection mold tool can be given the specific finish or texture desired on the pattern and hence the cast part.

Producing consistent, defect-free investment castings depends on optimization of metal flow. It may be that some modification of the part design is needed to ensure complete fill and an absence of cold shuts.

When to Use 3D Printing with Investment Casting

In conclusion, 3D printing of investment casting patterns is neither necessary or cost-effective in every case. However, there are a range of conditions where it can be faster, cheaper or yield superior metal parts. These are when:

- Mold tool manufacturing lead time is so long as to delay a launch or miss an opportunity or delivery date. In such circumstances case 3D printing gets parts to the investment casting operation in far less time.
- A requirement for relatively small quantities makes it uneconomic to pay for a mold tool. (These can cost thousands of dollars.)
- Part design requires complex re-entrant or overhanging features that can otherwise only be produced by metal 3D printing.
- Quantities are sufficient that metal 3D printing becomes too slow and/or needs too many machines
- Metal 3D printing is too expensive (due mainly to low print speeds, but also the cost of metal powders and the 3D machines.)
Explore Process Options with Casting and Machining Experts

By 3D printing rather than molding the patterns used in investment casting it’s possible to create metal parts with the design attributes of a printed part but at a cost closer to that of conventional investment casting.

Precise details depend on a variety of factors, including part size and the volume and type of metal needed. However, it is clear that 3D printed patterns extend the reach of investment casting into lower volume production and makes it an alternative to metal 3D printing.

If you are exploring options for manufacturing complex metal parts, talk to Impro. With deep expertise in sand and investment casting and precision machining, our specialists can advise on the optimal approach for your design and quantities. Contact us to start that conversation.