Investment Casting: Process Overview and Cost Reduction Considerations

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Finding its origins in ancient Egypt and China two millennia before the Xia Dynasty, investment casting is one of the oldest metal forming processes known to man. Yet, in spite of its 6000-year history, it is a relatively new manufacturing process, having its renaissance in the 1940s with the development of jet turbine engine technology.

Since that time, investment casting has found application in many of today's products, most of which are taken for granted. With more than 150 commercial foundries in the United States, plus numerous others around the world, today's global industry is estimated to produce $12 billion in raw castings annually. A significant part of this wide-spread growth comes from the process's capability to replace costly forms of manufacture on traditional products. Additionally, investment casting affords engineers greater versatility than other metal forming technologies when it comes to incorporating complex features into part geometry and specifying metallurgical processes to enhance component strength, thus improving component performance and longevity.

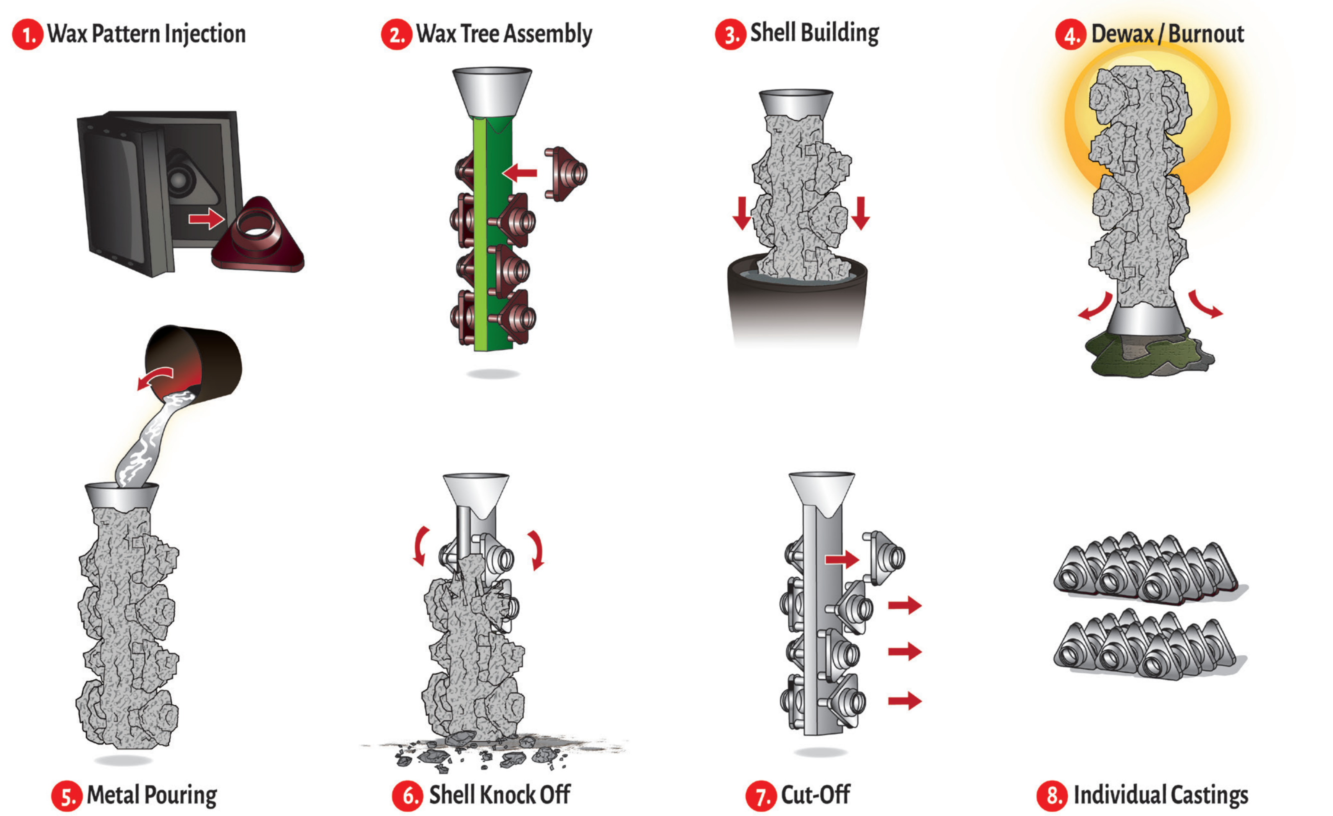
Process Overview and Capabilities

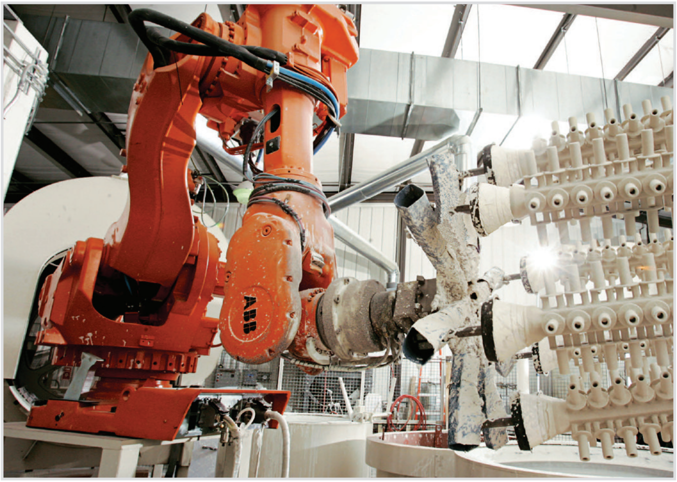
The investment casting process is comprised of several distinct steps, beginning with the injection of wax into a die, forming a wax pattern. Patterns are assembled onto a wax sprue with the final wax assembly representing the cavity into which metal will ultimately be poured.

This wax assembly, often called a "tree," is then affixed to a dipping handle to facilitate hand or robotic shell building. To build the shell, the tree is dipped into a ceramic slurry, backed up with stucco and allowed to dry in a controlled environment. This dipping process is successively repeated, laminating layers of ceramic material until the desired shell strength and thickness is achieved.

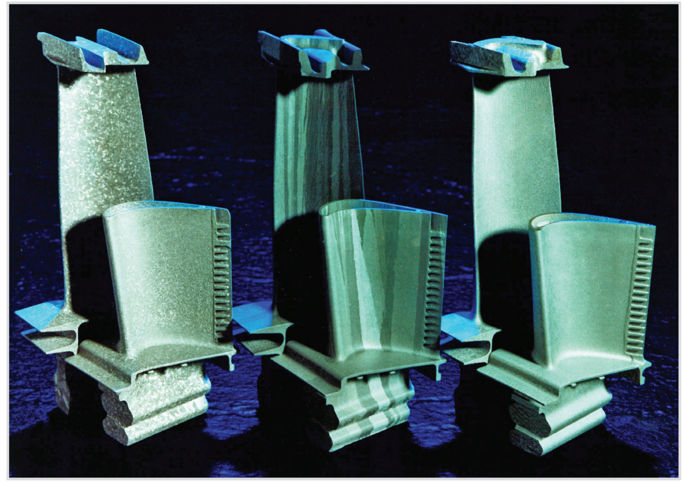
Please note that the ceramic shell also called a "mold," serves a one-time use and which will be destroyed later in the process.

The wax is then melted and removed from the mold, typically in a steam dewax autoclave, tunnel kiln or both. The hollow shell is then inspected and prepared for the casting process. Typical preparations may include the application of insulation to the mold in select areas to control rate of alloy solidification, thus ensuring part fill.





Shelling can be done by hand or with robotics.



Etched turbine blades exhibiting equiaxed grain, DS polycrystal and DS single crystal structure (L-R)

The mold is then preheated to a temperature accommodating to the prescribed metal pour temperature. Molten metal is then poured into the mold, filling the cavities and forming the parts. Though typically gravity poured, some foundries may employ the use of other casting technologies, such as vacuum, counter-gravity casting or even centrifugal casting.

The mold is then allowed to cool and the ceramic shell material, or investment, is then broken off and removed from the casting via a mechanical "knock off" process. The resulting parts are cut off the sprue, cleaned and finished. In some cases the customer may require additional metallurgical treatments be applied prior to final inspection and delivery.

The following are typical tolerances supported by the investment casting process.

Linear: 1" ± .010"; add .005" for each additional inch
Flatness: depends on geometry and alloy
Roundness: typically, .015" on 1" diameter Radii,
Fillets: commonly min .010"
Surface roughness: 125 RMS max
Wall thickness: depends on alloy selection

Capability will vary considerably from caster to caster; it is highly recommended that designers consult with a foundry when specifying tolerances in their designs.

Special Techniques

Depending on component requirements, investment casters may employ the use of special techniques to achieve desired results. Some of the factors that can drive the use of special techniques include component geometry, grain structure, volumes and time constraints.

Often, part geometries may call for internal passages or cavities. To produce these cavities, a foundry may employ the use of either ceramic or soluble coring in the wax injection process. To create an internal cavity in a part, a core is inserted into the die and wax is injected around it, creating a cored pattern. Soluble cores are removed prior to shell building in an aqueous solution, while ceramic cores, which are typically used for intricate internal passages, are removed after casting in a caustic solution under extremes of temperature and pressure.

In applications where enhanced component strength is necessary, a design engineer may specify a specific grain structure to accommodate those needs. The most typical grain structure is called equiaxed grain. This occurs when the mold is simply poured and allowed to cool without any additional processing. Additional processing during the solidification process can be employed to either create fine grained castings, a specialized form of equiaxed grain, or to grow grains into crystals through directional solidification (DS). There are two types of DS castings, poly-crystal, where multiple crystals grow in parallel through the part; and single crystal, where all but the primary crystal is filtered out during solidification, resulting in a part without grain boundaries. DS castings are most often used in jet turbine applications.

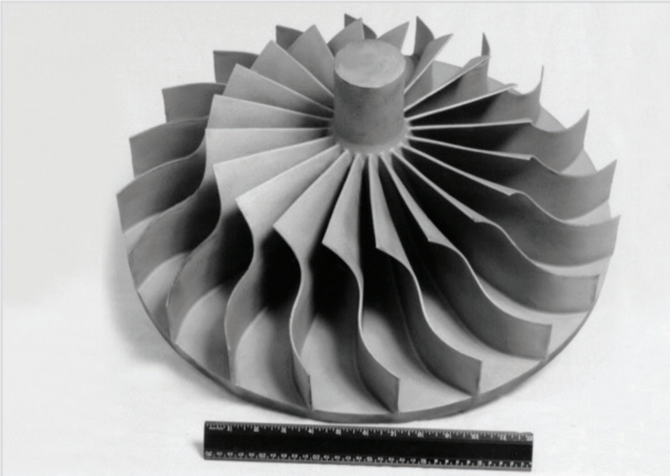
Rapid Prototyping

An alternate approach to the basic process may also be required when there is a need for prototype parts or when volumes are too low to economically support wax die construction. In these cases, a 3D model of the component can be used to produce stereo lithographic array (SLA) patterns, machined wax patterns or printed wax patterns. These patterns take the place of the injected wax pattern, and provide the designer with a cost effective solution to create small runs of parts in a timely fashion.

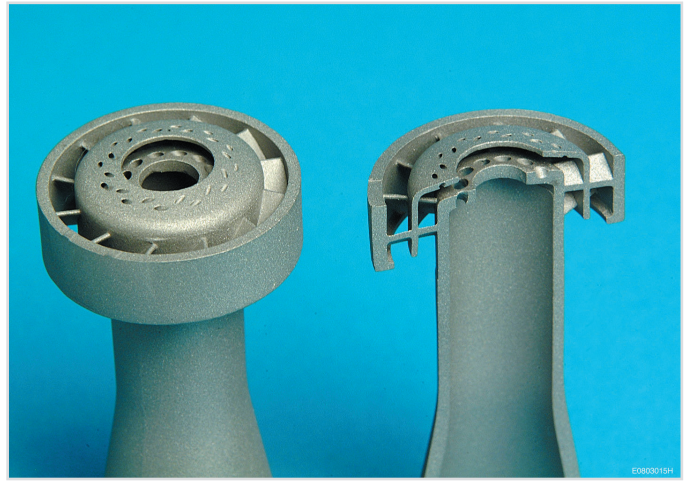
New Parts: Cost Effective Design

It is always beneficial to involve the foundry as early as possible in the component design process. Doing so will result in a shorter development times with a smoother transition to robust production. Additionally, seeking consultation from a foundry on component design is key to establishing a cost-effective approach.

Typically, many factors affecting manufacturing cost are controllable in the design phase. Conversely, cost increases with requirements. Dimensional tolerances, material selection, testing requirements and supporting documentation all play a role driving cost effectiveness.



Previously machined from solid stock, this impeller afforded the customer a 45% cost savings with a 40% reduction in lead time.



Swirler for gas turbine engine is small part which replaced 27-piece fabrication.

For example, when considering part dimensional tolerances, the cost conscience design engineer strives to incorporate the following concepts whenever possible:

- Make thick-thin transitions gradual
- Use radii and filets in corners
- Stagger intersections
- Account for machining stock

Consider post-cast processing such as straightening and surface finishing options.

Cost-effective part design is no accident. It takes planning and careful consideration of the more subtle cost drivers that can be overlooked. For example, a designer should refrain from placing datum targets on locations where gates will be located and never dimension a part from outside the part geometry.

A lack of clear requirements during the quotation process will also be a cost driver. It is important to be specific in the request for proposal process. Another consideration is the economic benefit derived from running prototype parts before finalizing all design requirements. Prototype components can offer the designer valuable information that can affect the long term cost of their design.

All of these factors, and numerous more, should be considered to effect a design suited for low-cost manufacturing. The best way to address these factors is to work with an experienced foundry before finalizing design, if not at the start of it.

Existing Parts: Casting Conversions

There are numerous metal forming processes in use today, and each of them has its place, but all too often, components currently in production are not being manufactured with the most cost effective process.

Investment casting can offer net-shape or near net-shape solutions to components that are currently being machined from solids. These components can have higher manufacturing costs than castings due to the inefficient use of material and excessive machine time. One such example would be that of an Inconel impeller that was formerly machined from solid stock. By resourcing this component as an investment casting, the original equipment manufacturer realized a 45% savings in unit cost as well as a 40% reduction in lead time.

Components made from fabrication or weldments can also present manufacturers a cost savings when manufactured as a single-piece casting by eliminating labor, decreasing lead time and enhancing component life. One such example would be that of a swirl nozzle for a gas turbine engine that was previously manufactured as a 27-piece weldment. This is a very complex part, with .070" and .030" holes at critical angles being machined into the part. The investment casting solution was to manufacture this as a one-piece casting, with the holes integrally cast into the product. This approach not only had a significant effect on component manufacturing cost and lead time, but it also extended the useful life of the part, thus reducing operational costs for the end user.

Is Investment Casting the Right Solution?

Investment casting is a versatile process that is used to produce parts ranging in size from as fraction of an inch to tens of feet in diameter. It affords the designer low-cost solutions to complex problems, and it is a proven approach to reduced cost of components being manufactured via other less effective means.

The only way to answer the question "Is Investment Casting the Right Solution?" is to talk with a foundry. The Investment Casting Institute is a non-profit trade association dedicated to facilitating and promoting the investment casting process. The Institute receives inquiries on a regular basis, and can offers guidance to manufacturers in locating foundries well suited to their needs.

Contact the Institute at 201-573-9770 for further case studies on investment casting or visit the Institute's website at www.investmentcasting.org.