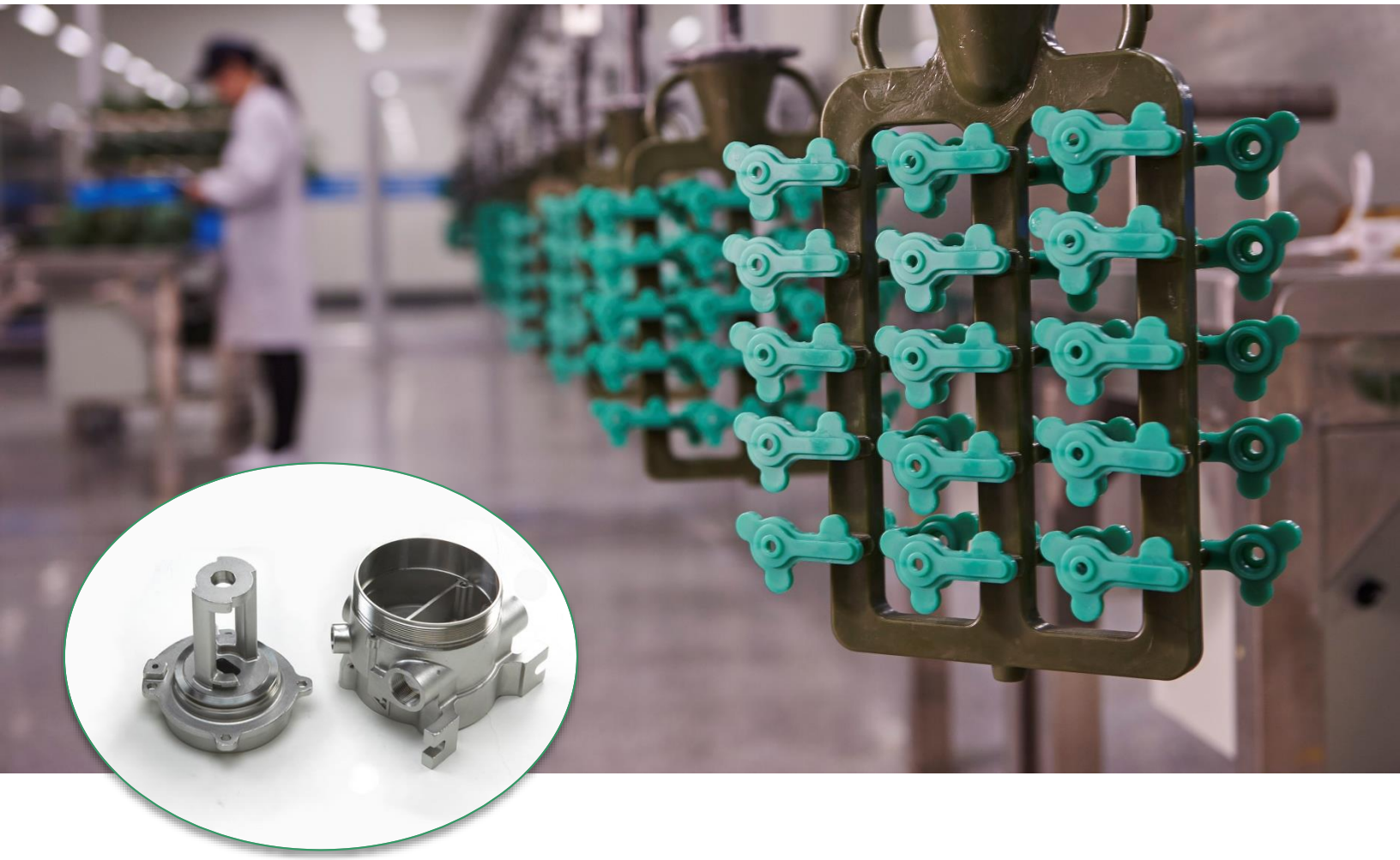
Impro

INVESTMENT CASTING

DESIGN GUIDEBOOK



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Investment casting is ideal for producing intricately-shaped metal parts. It delivers excellent surface finish and very high precision and is particularly useful when machining would be difficult and/or slow. However, like other casting methods, the only way to maximize its advantages is by designing to suit the process. This guide offers advice on when investment casting is appropriate and how to design accordingly. Sections address:

- Process overview
- Strengths and limitations
- Suitable metals
- Dimensional control
- Surface finish and appearance
- Casting defects
- Design considerations



PROCESS OVERVIEW

Like other casting processes, investment casting entails pouring molten metal into a cavity that's the shape of the part required. Where investment casting differs is in how that cavity, or mold, is formed.

Mold production starts with a wax pattern. This is an exact reproduction of the part that will be cast in metal. The wax pattern is formed by injecting wax into a mold or it may be 3D printed. As wax has a very low melting point no special materials or heating methods are needed. Cores placed in the wax will carry over to the metal pouring step to create channels and galleries as needed.

If necessary, the wax pattern will be trimmed by hand to ensure detail is sharp and no parting lines or flash are visible. Multiple patterns will be joined to a wax sprue to form a "tree" which is coated as a single assembly. The tree is then dipped in a ceramic slurry to give each wax pattern a hard coating.

Once the coating is dry the wax is melted out. (This is what has given investment casting the alternative name of "the lost wax process".) The void remaining is what will form the investment cast metal part. The ceramic shell is then preheated before metal is poured in.

Once the metal has solidified the ceramic shell is broken apart to release the cast parts. A new shell is needed to cast the next parts, which makes investment casting more like sand casting then die casting.



STRENGTHS AND LIMITATIONS

The fine particle size in the ceramic slurry ensures detail in the wax is carried over to the cast part. Likewise, the slurry takes on the surface finish of the wax part, which can be very smooth, (certainly much smoother than a sand cast surface.)

The process allows casting of very thin sections and delivers highly consistent dimensions with little distortion. For this reason, minimal machining allowances are needed: an investment cast part is close to finished and ready for use.

The ceramic shell will handle high melting point alloys, making investment casting appropriate for aerospace and aircraft engine applications.

Investment cast parts need not have any draft angles, parting lines or flash (unlike die cast parts.) However, these may carry over from the wax pattern unless removed at trimming.

Material utilization is better with investment casting than other casting processes. This makes it particularly attractive for casting higher value metals.

The biggest limitation of investment casting is economic. The process has many steps and even with extensive automation these add cost and extend lead time. Wax pattern dies are expensive to make and the ceramic slurry refractory materials are more expensive than casting sand. Thus, investment casting is most often used in medium to high volume applications. However, the costs must be set against the potential savings in finishing, especially in the case of complex forms that would need 5 axis machining.



A second limitation is the difficulty of using very small diameter cores, although parts may be cast with thin wall sections.

The complexities of the process, particularly the wax pattern manufacturing aspects, mean the process is generally used for smaller parts up to around 100 lbs. However, this process is also suitable for large castings up to 1,500 lbs.

SUITABLE METALS

An extensive range of metals are suitable for investment casting. The list goes from low melting point alloys of aluminum, copper and brass to stainless and carbon steels and super alloys like Inconel and Titanium. Even gold may be investment cast for jewelry. Certain alloys such as Inconel and Titanium require specific ceramic shells and atmospheric furnace processes due to their unique characteristics.

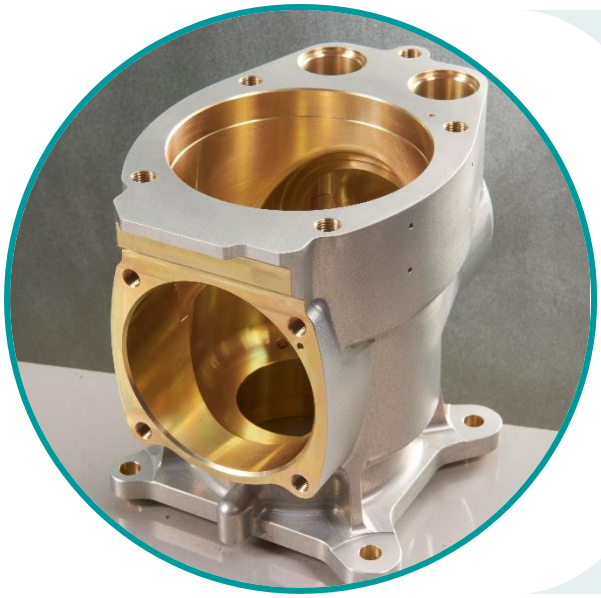
Part complexity will have an impact on metal selection. Some metals exhibit greater fluidity than others and so flow more easily into narrow sections. For example, stainless is more fluid than most low carbon steels.

DIMENSIONAL CONTROL

Part-to-part consistency largely depends on the wax patterns. If these came from a single mold variation will be minimal. Accuracy is also determined by the precision of the pattern, gating, shrink factor, shell system, and post-cast processing. A good standard tolerance to apply is +/-0.005” (0.127mm).

SURFACE FINISH AND APPEARANCE

The ceramic slurry faithfully reproduces the surface of the wax pattern, so it’s this which determines finish and appearance. In general, roughness of 125 µin Ra (3.2 µm Ra) is achievable. For this reason, while application-dependent, in many cases investment cast parts require little to no finishing.



CASTING DEFECTS

The defects that can occur in investment casting are similar to those seen with other methods of casting. These include:

- Distortion
- Nonfills
- Shrinkage
- Cold shuts

In addition, there is a risk of ceramic particle inclusion. This may happen if shells are mishandled.

Distortion and nonfill problems are usually a result of problems in wax molding. Asymmetric designs can result in differential cooling rates that twist and deform the wax shape. Insufficient venting is a primary cause of nonfills.

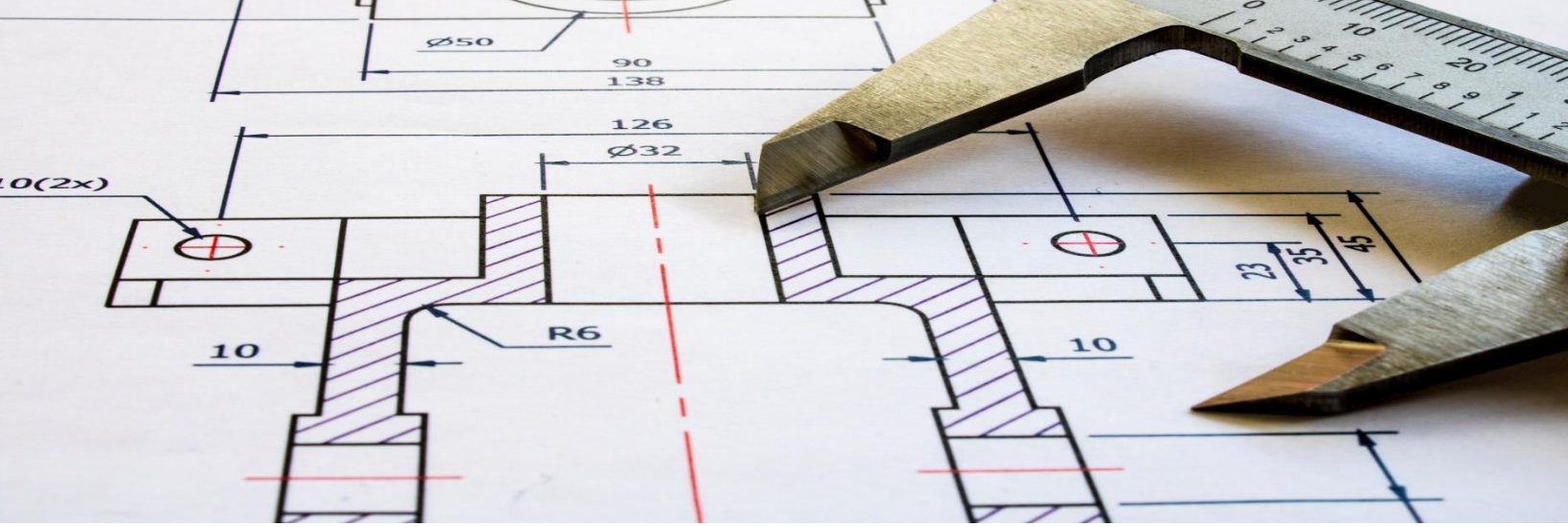
Shrinkage, which may manifest as voids within the castings, usually stems from the inherent casting design and how the metal solidified. Sprue and gate design are key to ensuring more metal can flow into the cavity as the metal already there cools and shrinks. Pouring temperature and shell thickness also influence shrinkage and cooling rate.

Cold shuts are boundaries within the cast metal. These arise when metal flowing in opposing directions is already solidifying as it meets in the cavity. Gate design, pouring temperature and cooling rate are the principal influences.









DESIGN CONSIDERATIONS

The quality of the parts produced by investment casting depends mainly on the quality and geometry of the wax pattern. However, it's also important to consider how metal will cool and shrink and the effect this may have on the final part.

Symmetrical shapes and uniform thickness walls will reduce distortion during cooling and solidification of both wax and metal. Including ribs and gussets in the design can also help.

Once the ceramic shell has been broken away the metal parts will still be attached to the sprue by gates and runners. The parts will be knocked or cut off, but some residual gate witness marks will remain. These will be minimized by placing them on flat rather than curved surfaces, which allows closer cutting.

From a process perspective, another point to consider is the thickness of the ceramic shell. While a thicker, and therefore stronger, shell is needed for heavier parts, greater thickness reduces cooling rate and increases metal solidification time. A corollary of this is that cooling rate affects microstructure and thus part properties. These points must be taken into account when planning the arrangement of wax patterns on the sprue.

SOME OTHER TIPS TO CONSIDER ARE:

- Wall thicknesses should not be less than 0.030" (0.76mm) and thicker than this on larger parts.
- Shrinkage will be most pronounced in the longest dimension of the part. The closer to square a part is the less shrinkage will affect dimensions. Where possible, keep length to width ratios under 4:1.
- Sudden or dramatic changes in cross section create a risk of cracking during solidification. Try to ensure a part or feature thins gradually rather than quickly. If possible, avoid thick-to-thin "hourglass" feature shapes, walls, and transition features.
- Combine what were previously individual parts into one investment cast part to reduce manufacturing costs elsewhere.

APPLICATIONS FOR INVESTMENT CASTING

The economics of the process mean that investment casting is most often used to produce complex parts from higher value metals in medium to high volumes. Aircraft engines make extensive use of investment cast components, but there are many automotive and industrial applications too. Manifolds, housings, clamps, and fuel injection components are just some of these. Even the mascot on every Rolls-Royce motor car is an investment casting!

COULD YOU BENEFIT FROM INVESTMENT CASTING?

The consistency and precision of investment casting make it a near-net shape process that saves on, and can even eliminate, machining operations. It also opens the door to further savings through high material utilization and the possibility of combining several smaller components into a single more complex casting.

Against these benefits though, investment casting is more complex than other casting processes and this inevitably adds cost and time. Taking full advantage of the process requires a thorough understanding of how to design for it. This guide has provided an overview but any designer or engineer considering the use of investment cast parts should discuss their application with a process expert. This may reveal additional cost reduction opportunities that help justify this decision.



INVESTMENT CASTING AT IMPRO

Impro is a leading manufacturer of investment cast parts and has made substantial investments in advanced technology to lower costs and raise quality This ranges from fully automatic wax injection machines to robotic pattern assembly and shell-making. Inefficiencies and costs are avoided because we are one stop: casting-machining + special processes. Learn how investment casting could benefit your business by starting a conversation with an Impro specialist today.

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