INVESTMENT CASTING

FORTUS
3D PRODUCTION SYSTEMS

Time Required Cost Skill Level

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OVERVIEW

Investment casting, also called lost wax casting, is widely used for producing ferrous and non-ferrous metal parts. Unlike other casting processes, investment casting produces net shape parts with excellent surface finish and dimensional accuracy. This manufacturing process is ideal for applications that have relatively low production quantities (10 to 10,000 pieces) or rapidly changing product designs.

Nearly 200 alloys are available with investment casting. These metals range from ferrous—stainless steel, tool steel, carbon steel and ductile iron—to non-ferrous—aluminum, copper and brass. When cast in vacuum, super alloys are also available. The only process that matches this breadth of materials is machining, but it cannot produce the complex geometries that investment casting can deliver.

Since investment casting uses expendable patterns and ceramic shells, it is excellent for complex and detailed part designs. The process manufactures intricate parts that are difficult, if not impossible, to machine, forge or cast. Examples include internal passages and ports in a valve body, curved vanes of an impeller and internal cooling channels in a turbine blade.

The critical barrier in prototype development and short-run production is the time and cost for injection molds. Each metal casting requires one wax pattern, and these patterns are injection molded. As design complexity rises, the tooling often becomes too costly and too time consuming to make prototyping and low-volume production practical.

FDM AND INVESTMENT CASTING

The key advantage of FDM (fused deposition modeling) is that it eliminates the need for tooling. Injection molds for wax patterns range from $3,000 to $30,000, and building the tools can take four to six weeks. With FDM, the tooling cost is eliminated and the lead time for a cast part is slashed to just 10 days on average. This yields a savings of $30,000 and two to four weeks for a typical project, which makes investment casting viable for prototype quantities (figure 1).

The time and cost savings are true no matter how complex the part's design. Since FDM is an additive fabrication technology, there is no impact on the investment or delivery schedule as the pattern becomes more complex. Another advantage, which is unique to FDM, is that the soluble support technology allows interior passages to be constructed. Additional time savings also occur in casting design, since FDM patterns can be produced without adding draft angles to the CAD data.

A final consideration is the durability of the pattern. Patterns made from foundry wax and other additive fabrication technologies are easily damaged. And, transportation and routine handling can result in broken patterns. The strength and toughness of an ABS part built on a Fortus 3D Production System virtually eliminates pattern damage and the delays it can cause. The ABS material is also resistant to distortion from heat, humidity and post curing which can be an issue with other additive fabrication technologies.

PROCESS OVERVIEW

The investment casting process begins with a pattern. Traditionally, the pattern was injection molded in foundry wax, but this is replaced by ABS patterns made on a Fortus system.

Gates and vents are attached to the pattern, which is then attached to the sprue. After all patterns are mounted to the sprue producing what is called a casting tree. At this point the

APPLIES TO MATERIALS:
- ABS, ABSplus, ABS-M30, ABS-M30i

SUPPLIES:
- Solvent
- Typical investment casting supplies

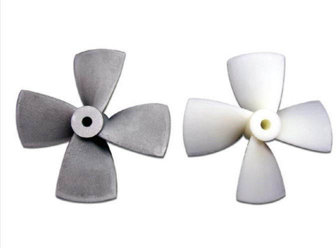

Figure 1: Investment casting (left) made from FDM pattern (right) eliminates tooling for molding of wax patterns.

Casting Design:
- Fillets: 0.030 inch min. radius
- Edges: Sharp to 0.020 inch min.

Casting Deliverables:
- Angles: +/- 1.0 degree
- Tolerance: +/- 0.005 inch
- Surface finish: 60 - 125 _in RMS
- Flatness: +/- 0.005 inch/inch
- Size: < 1 oz to 20 lb.
- Quantity: 1 to 5,000 typical

casting tree is ready for shelling. The casting tree is repeatedly dipped in ceramic slurry to create a hard shell that is called the investment. The patterns are then melted out (also called burnout) of the investment, leaving a cavity in the shape of the part to be cast.

A metal alloy is melted, often in an induction furnace, and poured into the preheated investment. After cooling, the shell is broken away, the metal parts are cut from the tree and the gates and vents are ground off.

PROCESS

Investment casting is a combination of science, experience and art. Prior to final design and pattern construction, it is important to select an investment casting foundry and initiate communications. Typically, each foundry will have unique capabilities, processes and requirements. In addition, pattern specifications will vary with the selection of the metal alloy and the geometry of the part.

If producing patterns for the foundry, it is critical that the foundry reviews the design so that it can recommend necessary design modifications to produce the highest quality part. The foundry can also make recommendations that reduce cost, time and weight, while improving castability and product performance. Finally, the foundry will provide shrinkage compensation, vent and gate design information.

Note that the following information is offered as a general guideline for production of investment castings from FDM patterns. Since each foundry has its own process standards and techniques, these guidelines may need slight alteration to adapt to a foundry's process. Additionally, FDM research is ongoing, so new process guidelines may evolve.

PATTERN DESIGN

Beyond good design practices, the key consideration is pattern modification to prevent shell cracking and minimize residual ash. Ceramic shells have a very low coefficient of thermal expansion, so any expansion of the pattern during the burnout cycle may cause the shell to crack. Additionally, Fortus material does not melt like wax, so it is burned out leaving a small amount of ash (0.021 percent) in the shell cavity. This ash is later removed in a shell washing process.

The pattern part interior style is modified to reduce the amount of material reducing expansion forces. This is achieved by building the pattern using the sparse fill build style in Insight, FDM's part processing software (figure 2).

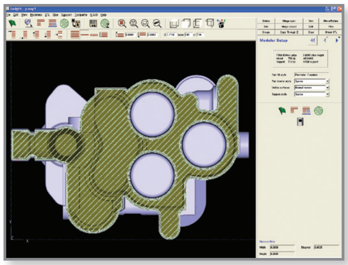

Figure 2: For sparse fill parameters, maximize the gap and reduce the road width to 0.003 inch (0.076 mm).

Adding foundry-defined gating and vents to the CAD model and constructing it as an integral part of the pattern. To facilitate shell washing, gates are added to opposite ends of the pattern. This gate configuration provides a flow path for water to flush out the residual ash from within the shell. Alternatively, the foundry can add wax gates and vents to the pattern. Vents are added to the pattern to assist in the burnout process.

The final step is to add machine stock and shrinkage compensation to the model. For machined surfaces, 0.020 to 0.030 inch (0.51 to 0.76 mm) machine stock is added to the CAD model. Shrinkage compensation, ranging from 0.007 to 0.020 inch/inch (0.18 to 0.51 mm), is then applied to the CAD data. The material shrinkage may vary in the X, Y and Z axes and will be dependent on model geometry and the selected alloy. Therefore, the foundry must supply these parameters.

PATTERN CONSTRUCTION

FDM investment casting patterns require no modification to the build parameters and build styles. One consideration is to orient the model to achieve the best surface finish and feature detail. Another consideration is to build the pattern using the finest layer resolution available. This will produce the thinnest walls promoting complete burnout without cracking the shell.

Presently, the only materials that have been validated for the investment casting process are ABS, ABSplus, ABS-M30 and ABS-M30i.

SUPPORT MATERIAL REMOVAL

Remove all supports, which can be either breakaway or soluble, from the patterns. After support removal and before making the shell, the part should be dried to eliminate moisture from the interior of the pattern. Place the pattern in a well ventilated area and allow it to dry thoroughly. To accelerate drying, place the pattern in an oven and heat it to a maximum temperature of 185° F (85°C). If using ABSplus, reduce the temperature to a maximum of 167° F (75°C).

PATTERN FINISHING

Prior to assembly and shelling, the pattern should have a smooth finish, and it should be sealed to prevent the ceramic slurry from entering the pattern (figure 3). One option is to use the

Finishing Touch™ Smoothing Station, which will remove layer lines and seal the surfaces of the pattern. If the Smoothing Station is not available, dipping or brushing the part in or with a solvent like Weld-On #3 or acetone will provide similar and suitable results.

If desired, the pattern can then be sanded to improve the surface finish. Alternatively, paste wax and acrylic paints may be used. However, before using either material, contact the foundry to make sure that it is compatible with its casting process.

PATTERN ASSEMBLY

If the pattern size exceeds the build envelope of the Fortus system, it can be split into multiple pieces and assembled. Join the pieces using Weld-On #3, a product that chemically bonds ABS plastic. Other bonding material may be used, but as with the finishing materials, contact the foundry to determine what materials are suitable.

CASTING TREE ASSEMBLY

If gates were not built as part of the FDM pattern, they are added at this time. Made from foundry wax, the gates are wax welded to the pattern. In addition to gates, wax vents should be attached to the FDM patterns. During the burnout process, the patterns will combust and release some gas. The vents allow the gas to escape during burnout and promote air flow for combustion.

To allow this airflow, drill holes into the FDM pattern exposing the sparse interior. These holes will be covered with the wax from the gates and vents. If the gates or vents were built into the model drill out the ends exposing the sparse interior, this will be covered by the wax when it attached to the sprue.

Next, the gated patterns are attached to the wax sprue, also with wax welding. When all patterns are attached, the casting tree is ready for shelling.

SHELLING

A ceramic shell, approximately 0.375 inches (9.53 mm) thick, is created around the casting tree. The result is the investment into which the alloy is cast.

The casting tree is dipped in a face coat of agitated ceramic slurry and then coated with a stucco of fine sand (figure 4). The face coat process is repeated and followed by four more coats of slurry. The shell is then dried under controlled conditions.

When using FDM patterns, additional layers of ceramic slurry should be applied to minimize shell cracking during the burnout process. For example, if a traditional casting tree made from wax patterns is shelled with seven layers of slurry, the casting tree made from FDM patterns should get 10 layers of slurry (figure 5).

After the shelling process is completed, cut the ceramic off of the vents exposing the wax or ABS vent. This process is critical in getting a complete burnout without cracking the ceramic shell.

BURNOUT

The critical modification to standard foundry procedures is in the burnout of the pattern from the ceramic shell. The standard processes of removing the casting tree by melting the wax in a steam autoclaving is not suitable for evacuation of the FDM pattern. Instead, a higher temperature, longer duration furnace cycle is required to burn out the FDM pattern.

Burnout procedure proven successful when using ABS patterns.

Step 1: Use the standard autoclave procedure to melt out the wax vents, gates, and sprue.

Step 2: Completely dry the shell by placing it in a warm, well ventilated location.

Step 3: Burn out the ABS pattern by placing it in a flash furnace and ramping the temperature up to 1600 F (870 C) – 1950 F (1066 C) for one to four hours. (Note: Work with the Investment Casting facility to determine the correct time and temperatures needed.)

Following the furnace cycle, inspect the shells to determine if burnout is complete. If needed, return the shell to the furnace and continue the burnout.

SHELL WASHING

To remove ash and ceramic dust, the shell is washed with a forceful stream of water. If using fused silica for the shell, it may be washed immediately after removal from the furnace. The water stream is allowed to enter one gate and exit through another gate or a vent. During washing,

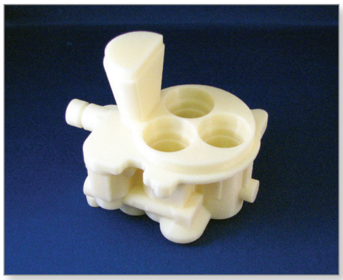

Figure 3: FDM pump body pattern, made from ABS-M30, is ready for shelling after sealing and sanding.

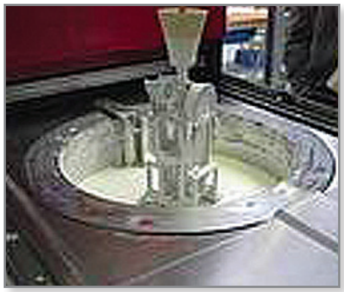

Figure 4: Shelling tree being dipped into ceramic slurry.

Figure 5: Parts on casting tree after shelling process.

the water is agitated by shaking the shell vigorously. The shell is then inspected to ensure that all residual material has been removed. Once the ash is removed the extra gates and vents are plugged with paste typically used to repair cracks in the shells.

CASTING

The completed shell is now ready to receive the molten alloy. The shell is preheated, and the alloy is cast into it according to the foundry's operational procedures. After cooling, the shell is broken away, and the castings are cut from the sprue. The gates and vents are then ground off. The casting is now ready for use or for secondary processes, such as heat treatment.

CONCLUSION

With FDM patterns, investment casting is practical for prototype and low-volume production applications. In less than two weeks, prototype castings in numerous alloys are ready for testing, evaluation or use. Making investment casting patterns out of Fortus ABS materials saves both time and money on low volume production applications as well as investment cast prototypes. .

With only minor modification to the pattern design and the burnout process, FDM technology eliminates the costly and time-consuming tool-making step needed for lost wax casting. With this process guide and the skills of a qualified foundry, companies in all industries can capitalize on the efficiency, capability and quality of investment casting.

FDM PROCESS DESCRIPTION

Fortus 3D Production Systems are based on patented Stratasys FDM (Fused Deposition Modeling) technology. FDM is the industry's leading Additive Fabrication technology, and the only one that uses production grade thermoplastic materials to build the most durable parts direct from 3D data. Fortus systems use the widest range of advanced materials and mechanical properties so your parts can endure high heat, caustic chemicals, sterilization, high impact applications.

The FDM process dispenses two materials—one material to build the part and another material for a disposable support structure. The material is supplied from a roll of plastic filament on a spool. To produce a part, the filament is fed into an extrusion head and heated to a semi-liquid state. The head then extrudes the material and deposits it in layers as fine as 0.005 inch (0.127 mm) thick.

Unlike some Additive Fabrication processes, Fortus systems with FDM technology require no special facilities or ventilation and involve no harmful chemicals and by-products.

For more information about Fortus systems, materials and applications, call **888.480.3548** or visit **www.fortus.com**

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