6. Rapid Tooling & Metal Parts by Additive Fabrication

Rapid Manufacturing; A Brief Synopsis

As discussed in the previous chapter, parts made by rapid prototyping systems may be used directly in many final applications today. This reflects great strides in materials and machinery that have been spurred by insistent market forces over many years. Additively-fabricated parts may well offer a direct solution to application problems having material requirements ranging from plastics or ceramics, to steel or titanium.

Additive fabrication is making its greatest headway in manufacturing applications that take advantage of its unique benefits. It has become an accepted solution for fabricating geometrically-complex, low-volume or customized parts. RP is also recognized as a means to produce parts and tools in forms and combinations not otherwise possible, such as in the use of gradient or multiple materials. While many applications are still in the development stage their potential range is vast, extending from the microscopic scale of nano-devices and integrated circuits to the construction of entire buildings, boat hulls and the like. In some cases additive fabrication's nominal liabilities are being turned into advantages. For example, the capability of some RP technologies to create porous parts is being found useful in fabricating complex filters, gas storage devices and similar products.

- Descriptions of many of the RP technologies available for rapid manufacturing are provided in the sections under Commercially-available Processes. Also see the accompanying technology comparison tables at the end of this chapter.

- See the Rapid Manufacturing chapter for an extensive exploration of the enormous potential of this application of additive fabrication.

Direct Fabrication of Plastic Parts

Plastic parts are most often directly fabricated for end use using selective laser sintering (SLS), fused deposition modeling (FDM) or stereolithography. Other technologies are also used, but these are the main ones that are of commercial importance at present. The choice of a technology is most greatly influenced by the end-use material requirements.

The development of photopolymers for use in stereolithography and similar light-based technologies has led to materials that exhibit a wide range of properties. Materials are available that mimic the mechanical properties of polypropylene and other plastics, exhibit flexibility for snap-fits and have optical properties such as high transparency. Efforts are ongoing to develop specialized photopolymers to widen their applications. Materials with properties such as low shrinkage, rubber-like flexibility and thermal conductivity, or to address specialized applications such as the construction of scaffolds for tissue engineering are either in development or have already been introduced.

While today's materials can solve many problems and the future looks very promising, photopolymers are analogs of engineering plastics. They may not possess all of the properties required for a particular application, and in some cases their properties may not be stable over time.

Both selective laser sintering and fused deposition modeling can produce parts in final engineering polymers. They may offer solutions when photopolymer-based technologies cannot. SLS can be used to fabricate parts in several types of engineering plastics, including glass-filled nylon. FDM can fabricate parts in ABS, polyphenylsulfone, polycarbonate, polyester and a few other materials. These technologies may offer parts with additional strength or other properties not currently available from photopolymers. One thing to note is that the properties will not be quite the same as a part fabricated in an injection molding process of the same material, however. How the additive fabrication machinery builds the part influences those properties to a considerable extent.

Direct Fabrication of Metal Parts

Metal parts are most often directly fabricated with selective laser sintering or laser powder forming processes. Here again, other technologies can be and are used, but these are the most commercially important ones at the moment. SLS and related technologies can be used to fabricate parts from steel, stainless steel, bronze and other materials. When required, porosity can be eliminated by secondary metal infiltration. Parts usually need final machining and their properties will not be quite the same as parts formed entirely of the intrinsic material. Laser powder forming processes can produce parts in steels, titanium and other metals at full density. However, this desirable characteristic may have to be traded-off against somewhat higher finish machining requirements compared to technologies in the SLS family. Direct fabrication of metal parts is finding its greatest application in high value-added applications such as aerospace and medicine.

Rapid Tooling; An Application of Rapid Manufacturing

While there is much progress in direct part fabrication, even the fastest rapid prototyping systems are far too slow and limited in other ways. They simply can't produce parts in a wide enough range of materials, at a fast enough rate, to match the enormous spectrum of requirements of industry. Conventional processes such as molding and casting are still the only means available to do that. However, additive fabrication is often the starting point for making these manufacturing processes faster, cheaper and better. Indeed, the fabrication of tooling is one of the most important application of rapid manufacturing, and provided much of the early impetus for the development of the field.

Rapid prototyping is used in two ways to make tooling: Molds or other tools may be *directly fabricated* by an RP system, or RP-generated parts can be used as patterns for fabricating a mold or tool through so-called *indirect* or *secondary processes*.

DIRECT FABRICATION PROCESSES

Specialized rapid prototyping processes have been developed to meet specific application and material requirements for molding and casting. These may be forms of basic RP processes, such as stereolithography or selective laser sintering, or may be unique RP methods developed for a specific application. A large number of technologies have been or are being explored, but only a relatively few are commercially important at present.

INDIRECT OR SECONDARY PROCESSES

Although the properties of rapid prototyping materials continue to improve and expand, their comparatively small number and a limitless array of applications means that there will always be a need to transfer parts fabricated in a material used in an additive fabrication process into yet another material. Consequently, numerous material transfer technologies have been developed. Typically a part made by the RP system is used as a p
direct fabrication processes discussed abo

but not as great as that with epoxy tools. The resultant mold core and cavity inserts are porous, and it may be necessary to infiltrate them with epoxy or low melting temperature metal prior to use. As many as several thousand relatively simple parts have been produced from such DMLS molds. In addition to limited life, soft metal tools generally can't reproduce fine detail and must be finished before use.

3D Systems formerly offered a similar process using a copper polyamide material.

Hard Tooling and Metal Parts

3D Systems' selective laser sintering process for metals uses polymer-coated steel powders. The resultant green part is burned out, sintered and infiltrated with bronze in secondary furnace operations to produce a fully-dense mold with about 70% steel content. These burn-out and infiltration procedures typically take about a day. The SLS metal part fabrication process has been greatly improved over the years to improve accuracy and resolution, and reduce stairstepping. The latter are critical improvements for hard tools because it doesn't make much sense to be able to quickly produce a hard steel tool if lengthy hand finishing and final machining eat up that advantage compared to CNC.

EOS's competing DMLS process for bronze alloys and steel powders doesn't require secondary sintering and burnout cycles in a furnace because the parts produced are already at 95% density. This is a result of a difference in the basic philosophy of how each company has designed its machinery. EOS has chosen to build separately optimized systems for plastics and metals, while 3D has chosen to build more flexible systems which can utilize both classes of materials. The EOS metal part producing machines use more powerful lasers which result in increased density after sintering. Indeed, in some scanning areas the metal is completely fused.

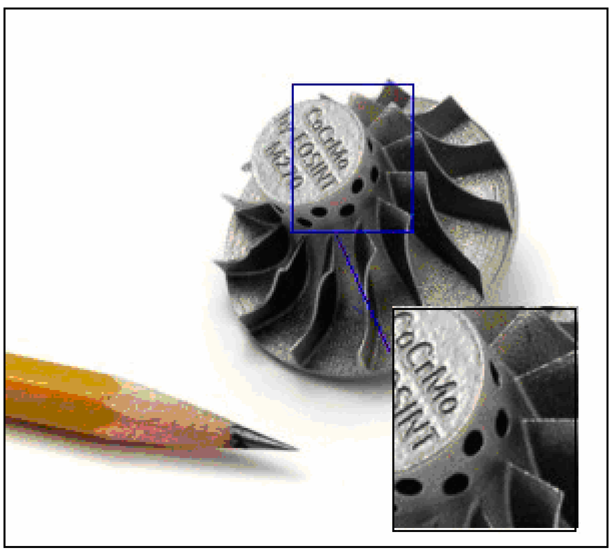

Fig. 6.2. Cobalt-chrome impeller made by laser sintering.
(Courtesy, EOS GmbH.)

EOS has also paid a great deal of attention to limiting the amount of secondary finishing required and they claim that customers often use their molds for production after simply a quick shot peening. Both steel and alloy metal powders are available that produce 20 micron (0.0008 inches) layers.

These steel-based processes offer the greatest benefit for
be difficult to machine. Conformal cooling channels can
last for hundreds of thousands of shots of almost any plas
conformal cooling channel geometry, however, to make c
be removed after fabrication.