Applications of FFF in The Metal Casting Industry

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Abstract

Fast Freeform Fabrication (FFF) is widely used in the casting industry, for tooling in sand casting, investment casting and die casting to save time and to take advantage of the variety of build materials, e.g. polymer, paper, ABS plastics, powder, wax and so on. A FFF process chosen to make patterns or cores depends on the nature of the casting processes, the availability and capability of the FFF machines among other requirements, e.g. production volume, accuracy, time, cost, and durability. This paper investigates applications of FFF in foundry processes. Issues discussed include the application of FFF models and the limitations and frontiers of those applications.

Key words: Fast Freeform Fabrication(FFF), casting, mold, master pattern.

Introduction

Fast Freeform Fabrication(FFF) refers to the physical layered production of digital design representations using a special class of machine technology. FFF systems quickly produce models and prototype parts from computer-aided design(CAD) model data, CT and MRI scan data, and data created from 3D object digitizing systems. Using an additive approach to build shapes, FFF systems join liquid, powder and sheet materials to form physical objects. Layer-by-layer, FFF machines fabricate plastic, wood, ceramic, and metal parts using thin, horizontal cross sections of the computer model[1]. Table 1 gives a brief overview of several FFF processes.

Casting is a pervasive material forming process in which parts are produced by casting melt material into precise molds. It is estimated that more than 90% of metal parts are created by sand casting processes[2]. Figure 1 shows a cross section view of a typical sand casting mold with terminology defining significant features[3].

Market competition has intensified in all industries with the advent of information technology and global economy. Companies are experiencing increasing pressure to reduce product introduction lead time and cost as part of their continuous effort to gain and sustain competitive advantage. These pressures have led to far reaching new developments in the fabrication of tooling for traditional manufacturing processes such as casting. In particularly, it is now possible to generate tooling directly from a CAD database by using a variety of fast freeform fabrication processes. These methods are widely referred to as *rapid tooling*(RT) processes because the tool geometry is created in relatively short time[4]. In this manuscript we limit our discussion to Rapid Tooling in foundry processes.

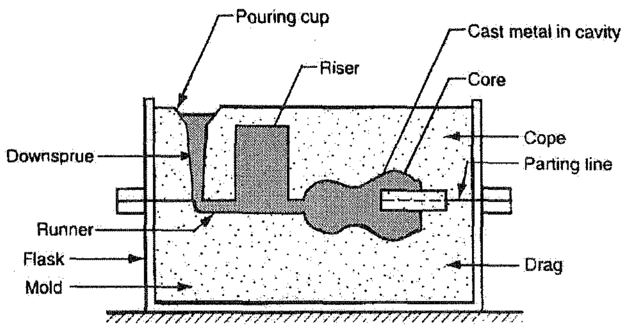

Figure 1. The cross section view of the typical sand casting mold

OEM	FFF process	Raw materials
3D Systems	SLA	Acrylate and epoxy photopolymer resin
Cubital	SGC	Acrylate and epoxy photopolymer resin
DTM	SLS	Nylon,polycarbonate ,copper polyamide, resin-coated sand and polystyrene
Helisys	LOM	Paper, sheet plastic, Glass-ceramic composite, ceramic tape and metal tape
Stratasys	FDM	ABS, elastomer, investment casting wax
Soligen	DSPC	Ceramic powder, polymer binder
Z Corp.	3DP	Starch-based powder

Table 1. FFF Processes

Figure 2. is an illustration of how companies are using FFF models at present. From the chart, we can see that about 28% of FFF models are being used as patterns for prototype tooling and metal casting, as well as for tooling inserts.

Casting Methods

Casting is a manufacturing technology with a history of about 5,000 years[5]. At present there are numerous methods of making a casting by either expendable, permanent or semi-permanent mold techniques. In this paper, we limit our investigation to sand casting, investment casting, die casting and plaster molding. Each method has its own advantages and disadvantages.

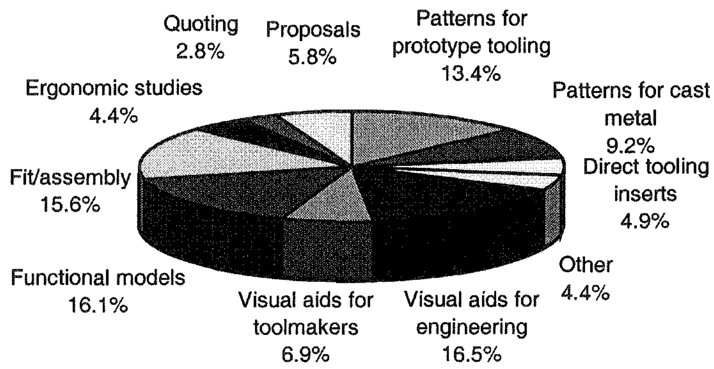

Figure 2. Applications of FFF in Industry[6]

Sand Casting

As its name implies, this process uses sand as the material to make the mold cavity. It is an expendable mold process because the mold must be destroyed to remove the casting. Tooling for this process consists of a pattern that is rammed with sand and removed to form the casting cavity.

Advantages: Most metals can be cast by this method. Pattern costs and material costs are relatively low. The method is adaptable to large or small quantities.

Disadvantages: There are practical limits to complexity of design. Machining is often required to achieve the finished product. Dimensional accuracy can not be controlled as well as with other molding processes, though accuracy is achievable with quality pattern equipment, modern process control, and high-density molding[5][7]. Thin, deep sections and very thin walls are difficult to cast.

Investment Casting

Investment casting denotes the mechanical manner of obtaining a mold rather than the material used. It is the process of completely investing a three-dimensional pattern to produce a one piece

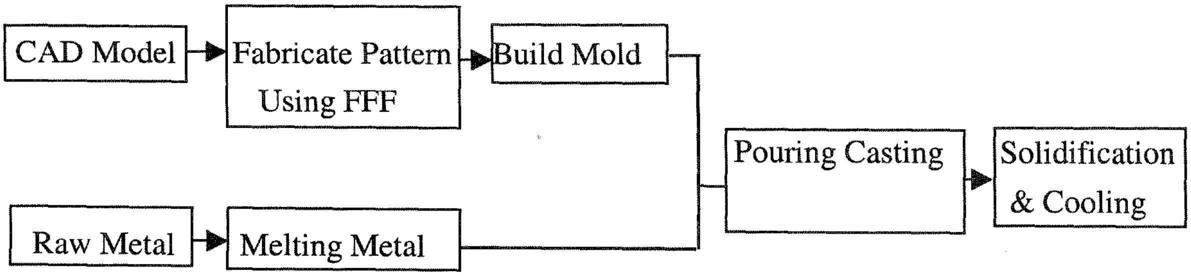

Figure 4 Indirect Method of Rapid Tooling

SLA and SGC patterns can be used in sand casting, investment casting and plaster molding. SLA Quickcast patterns are commonly used for direct investment casting. SLA patterns can also be used to produce wax patterns for investment casting by creating a silicone rubber negative mold from FFF masters and casting wax into the cavity. Companies can also use patterns made by SLA and SGC as master patterns in sand casting and plaster casting. In sand casting, if large number of castings are required, patterns are used to make a match plate type of tool. Because the plaster mold is not as abrasive as a sand mold, SLA and SGC patterns can be directly used in plaster molding even when high volume production is desired[8].

SLS patterns can be used in sand casting, investment casting, die casting and plaster molding. In sand casting, SLS can be used in the same manner as other FFF patterns are used. Mostly, SLS patterns are used in temporary tooling to make wax patterns in investment casting. One characteristic of SLS is SLS can make the mold for sand casting directly. Parts cast using FFF sand method display mechanical and physical properties similar to the parts cast in a production sand foundry[8]. This process allows cores to be integrated into the mold as it is built, providing a method to build parts with virtually no limitations on complexity. But due to the expense, this method has been limited to parts with complex geometry.

Although die casting and injection molding are similar processes, i.e., injecting a liquid material into a die under pressure, the die material characteristics and requirements are quite different. The molten die casting materials are less viscous than the polymer melt in injection molding and have greater tendency to flow between the contacting surfaces. The combination of flashing and high injection temperatures requires the die casting dies to be more robust[9]. A recent study by Peter J. Hardro & Dr. Brent Stucker has demonstrated the feasibility of die casting into RapidSteel 2.0 and has indicated that composite tools made via FFF can be used for die casting.

When just a few castings are required, a LOMPaper™ patterns can be used to make direct impressions in sand. Typically, a LOM pattern can create up to 50 sand molds if geometry is not too complex. Upwards of 100 replications can be taken from such patterns, if proper care is taken. If higher number of castings is required, LOM patterns can be used to produce master patterns or match plates. Also, LOM masters can be used as a one-to-one replacement of wax masters in investment casting. LOM masters however behave substantially different from wax. With wax, temperatures above 77 °C are sufficient to melt the master with nothing left in the shell. LOM masters on the other hand have to be flash fired at temperature higher than 574 °C The ash left in the shell is either blown out with compressed air or flushed out with water. A LOM pattern is not the best choice for direct use in the plaster molding process because of the moisture in plaster can be absorbed by the LOM pattern.

Like other forms of fast freeform fabrication, FDM patterns can be used in sand casting, investment casting and plaster casting. Wax patterns made by FDM can be directly used in investment casting. ABS patterns are suited to sand casting and plaster casting. It is also reported that FDM ABS patterns are suitable for use in investment casting[10]. Removing the ash requires an additional step when casting with a FDM ABS pattern.

Here, we should also mention DSPC(Direct Shell Production Casting) which produces the actual ceramic molds for metal casting. Three Dimensional Printing is used in this method[8]. First, design a virtual pattern for net shape casting, including a gating system through which molten metal will flow. Then create a digital model of the mold and transfers the model to the 3DP system. The mold includes integral cores to produce hollow sections. The 3DP system automatically generates the mold from thin layers of ceramic powder. After lowering the previous layer, a new layer of powder is spread. Then, liquid binder is "printed" onto the powder layer to define a cross section of the mold. The process is repeated until the entire mold is printed. This is then fired, resulting in a rigid ceramic mold surrounded by unbound powder. The unbound powder is removed from the mold. The last step is to fill the mold with molten metal at our foundry. After the metal solidifies, the ceramic and gating metal are removed and the part is finished.

Conclusion

This paper has discussed the applications of several major FFF processes in the tooling of sand casting, investment casting, die casting and plaster mold casting. The FFF processes can be directly or indirectly used in casting processes. The application depends on the material used by the FFF process, the production volume and the geometric complexity of the part.

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