AC 2007-44: RAPID MANUFACTURING VIA METAL CASTING

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Rapid Manufacturing via Metal Casting

Abstract

The metal casting industry in undergoing significant changes and it is necessary for manufacturing engineering, industrial engineering and design students to recognize these changes. Rapid manufacturing has the potential to revolutionize the metal casting industry by greatly reducing the tooling requirements necessary to produce components. The lead times to produce complex components are being reduced from months to days. A large reduction in the traditional labor requirements for molders, coremakers, patternmakers, and toolmakers will occur. The numerous advantages of the process are discussed and the major limitations are also presented. The "Third Wave" has arrived in the metal casting industry.

Introduction

Metal casting is undergoing significant changes in the developed countries to become less labor intensive to be cost competitive with developing countries with low labor costs through rapid manufacturing. Rapid manufacturing is considered to be part of the "Third Wave". The first wave was the agricultural revolution, then the industrial revolution and now the information revolution. Rapid manufacturing is also referred to as additive fabrication, direct manufacturing, digital production, rapid prototyping, free-form fabrication or layered manufacturing and is part of concurrent manufacturing. Rapid manufacturing transforms engineering design files into fully functional components. In metal casting the component produced can be a direct replica of the part such as a consumable pattern or the inverse replica such as a consumable mold for the production of the desired part. The key in rapid manufacturing for casting is the elimination of the tooling required to produce the consumable pattern or the permanent pattern. The tooling production takes the longest amount of time in the process from design to finished product and this step is reduced from months to days. This is essential in the development of new products or in the rapid production of critical spare parts.

Rapid manufacturing is a component of concurrent manufacturing which entails drastically reducing the time between product conception and product realization[1]. The recent technology developments in metal casting are based on the 3D printing concept to convert computer design files of three dimensional objects into physical objects such as patterns, cores, or molds to produce fully functional components. The emphasis is on the fully functional components, not look-like components, as the castings produced are of the metal desired for the component. Just as the 3D CAD permitted the metal cutting industry to develop new equipment for more rapid manufacturing and become more competitive, the use of 3D printing will permit the metal casting industry to be more productive and less labor intensive. The reduced labor content will allow the highly developed countries with high labor costs be more competitive with the developing low cost labor countries in the global market place.

Metal Casting and Rapid Manufacturing

There are several different approaches to part production using rapid manufacturing techniques that can be applied by metal casters and some of these are presented in Table 1. One of the first methods developed was the production of consumable patterns, such as those made from wax, starch or lost foam. A pump manufacturer used the process to produce starch patterns for the replacement of critical parts. The production often started without a drawing and only the worn out part was available. A coordinate measuring machine (CMM) was used to digitize the part and build a solid model. The solid model was sliced or layered and a starch pattern was produced which was then cast as a fully functional component and sent to the machine shop for finishing operations. The time was reduced from months to days because of the large reduction in design time and the elimination of conventional pattern production. The ability to make parts rapidly is critical to survival and this was the most profitable line of business for the company as customers were willing to pay more for faster delivery of the product for critical parts.

Table 1. Casting Approaches to Part Production Utilizing Rapid Manufacturing

Approach	Typical Use
Consumable Molds	Produce Sand Molds for Production Parts
Consumable Cores	Produce Sand Cores for Complex Castings
Consumable Patterns	Produce Consumable Patterns (starch and lost foam patterns)
Permanent Patterns	Polymer Patterns Which Can be reused to Produce Consumable Wax Patterns for Investment Castings
Sintered Preform Parts	Produce a Metal Preform Which Can be Sintered and Then Infiltrated with another Metal
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Spare parts production can be made rapidly as tooling is not required. This is essential in emergency situations, such as for aircraft in military operations such as Iraq where wear on parts was more severe than expected or in disasters from hurricanes or earthquakes. Small parts, such as gold dental copings which are a part of a dental crown, can be produced in groups of six in one hour. Thus a dental restoration can be produced in one or two days instead of a week[1].

There are numerous potential benefits for the metal casting industry in the application of rapid manufacturing, some of which are listed in Table 2. The advantages can lead to considerable cost and time reductions in the metal casting process. One of the major advantages is the reduction in material handling as cores tend to be fragile and break during handling. Material handling losses for cores often approach ten percent and are higher for fragile cores. The need for core boxes can be eliminated when cores are eliminated or produced with the mold.

Table 2. Rapid Manufacturing Advantages and Disadvantages in Metal Casting

Advantages

1. Reduced Time from Part Drawing to Manufactured Part (50-75% reduction in time from design completion to product completion)
2. Reduced Workforce Requirements because of reductions in:
   - Traditional Molders
   - Traditional Patternmakers
   - Traditional Coremakers
   - Material Handling
   - Storage for Production Patterns and Core Tooling
   - Reduced Cleaning
3. Reduced Tooling Requirements for Production
4. Traditional Patternmaking Effectively Eliminated
5. Pattern Storage Effectively Eliminated
6. Core Boxes and Traditional Coremaking Reduced
7. More Complex Molds Possible with Reduced Core Requirements
8. More Complex Cores to Reduce the Number and Assembly of Cores
9. Production of Molds and Cores Simultaneously
10. Reduced Core and Scrap Losses from Less Material Handling
11. Reduced Cleaning from Less Flash
12. Small-to-Medium Production Quantities Obtained Rapidly for Small Parts
13. Reduced Scrap from Mold/Core Breakage during Material Handling
14. Fewer Draft Problems as Zero and/or Negative Draft are Permitted
15. Gating Can be Designed into Mold
16. Risers/Feeders Can be Designed into Mold

Disadvantages

1. Difficult to Produce Large Products in High Production Quantities
2. Rough Surface Finish Due to Steps in 3D Layer Process
3. High Initial Equipment Costs
4. Higher Computer Design and Programming Skills Required
5. Low Production Rates of Molds (1 per day versus 1 per minute)
6. Difficult to Produce Hollow Cores(such as shell cores)

Pattern storage is effectively eliminated as the computer files will require negligible space. In many metal casting facilities, the pattern storage area is the largest area in the facility. The need to return patterns to the customer or store patterns for several years before one is permitted to dispose of the pattern will be eliminated. Core boxes also must be stored until required for use and these will be greatly reduced as the cores can often be made simultaneously with the mold. Since the number of core boxes will be reduced, the number of core machines to produce the cores will be reduced.

Finding skilled molders, coremakers, patternmakers and tool and die makers is difficult as the interest in this type of work is low in developed countries. Foundries have difficulty getting skilled employees and the turnover rates are high, but the need for these skills will be greatly reduced in the rapid manufacturing environment. The cleaning room requirements will be reduced as the flash will be less and tolerances will be better with fewer cores and better core assembly into the mold. Also, negative draft can be permitted which reduces the number of cores required and/or the amount of machining or grinding required to remove the excess material. However, more computer skills will be required as more simulation will be used to eliminate solidification and fluid flow defects. The computer and mental skills tend to be more appealing to youthful workforce rather than the physical skills of molding, coremaking, and patternmaking. Computer simulations will permit testing of alternative gating and risering/feeding designs to eliminate defects and improve yield. The simulations will also permit better determination of the amount and location of the shrinkage allowances needed to reduce finishing operations and improve yield.

The development of consumable sand molds and cores has been developed by ProMetal, a division of the Ex-One Corporation. The mold material is silica sand and a furan based binder system with approximately two percent resin is used. The largest machine build volume is 1500mm x 750mm x 700mm(depth), that is approximately 60"x 30"x 28". It takes approximately 1 minute per layer and the layer thickness can be set from 0.15 mm to 0.40 mm (0.006 to 0.015 inches). Thus it would take 1-3 days to build a large mold. The large build volume can be used to produce a batch of small parts in a single mold, produce a few medium size parts in the mold, or produce one large part in the mold. Machines with a smaller build volume would take less time per layer and the reduced mold depth will reduce the number of layers. The thicker the layer, the more noticeable is the step between the various layers. The use of mold washes has the potential of reducing the appearance of the steps between the layers. The 3D printing process will permit small companies to produce a wide variety of small batch products as the machine can work on a mold unsupervised during second and third shifts.

Technikon[2] uses a different process and produces ceramic molds and cores instead of sand molds and cores. The mold is an assembly of numerous mold and core parts to make the completed mold assembly for production. However, the key to the process is the elimination of the traditional hard tooling for the patterns and cores.

Figure 1 shows the drag and cores for an Intake Manifold of a V-8 engine. The time to build two molds (cope and drag) and cores for two intake manifolds was 14 hours. If one looks closely, one can notice the layered steps on the surface of the casting. Figure 2 illustrates the cope, drag, and cores for an engine block. The time to produce the components was 33 hours. Normally it would take months to get the tooling to produce these parts by traditional conventional molding and coremaking. Core and mold parts produced simultaneously in the same build volume of the machine are illustrated in Figure 3.

The 3D printing was used on polymer materials to permit the development of polymer molds which were used for the production of wax patterns for the investment casting process. Similarly, the use of metal materials in the 3D printing has permitted the development of metal sinter preform parts and molds. These parts are then sintered and then a lower melting temperature metal is infiltrated into the pores of the sintered product to produce the part. This has been done with steel powders and they have been infiltrated with a bronze alloy to produce materials for molds with a hardness between 25 and 35 on the Rockwell C scale.

The 3D printing concept further advances the metal casting industry into lean manufacturing. The lead time is greatly reduced, tooling requirements for patterns and cores are minimal, material handling is reduced, scrap rates will be lowered, more complex shapes can be produced and storage locations for patterns and core boxes become negligible. A small workforce is possible and thus the facility can be located near the customers

Rapid manufacturing will revolutionize the molding part of the metal casting operation for most of the smaller low-production and job shop foundries. Since the tooling is greatly reduced, more variations in designs can be evaluated to develop better components and products. More innovation can occur as the costs of prototypes will be reduced as fixed tooling changes will not be required. Similarly, it will not be necessary to have high volumes of production to justify the high costs of fixed tooling and thus more product variation and innovation can occur.

Educational Aspects

The drastic changes from rapid manufacturing in the metal casting industry are essential for the survival of metal casting in the developed nations. Students must be educated in the new technologies of rapid manufacturing for the metal casting industry to survive in developed countries. The computer simulation methods have reduced the problems of gating and risering in the foundries, and rapid manufacturing will reduce the high costs of patternmaking, coremaking, and other tooling requirements of the casting process. The reduction in direct labor requirements is essential for metal casting to survive in developed nations and the engineers of tomorrow must be aware of the capabilities rapid manufacturing in metal casting. Students must be educated in the rapid manufacturing processes, including metal casting, for the US manufacturing base to survive. The Wohlers Report[3] indicates that rapid manufacturing will be the main application for additive fabrication whereas currently it is mainly applied for rapid prototyping.

Rapid manufacturing concepts can be introduced in the manufacturing processes course(s) taken by industrial, manufacturing, and mechanical engineering students. It could also be applied in the engineering design course as it extends design into manufacturing. If the parts are designed by solid modeling, they can be produced directly by making a sinter preform part or by making a mold and then casting the part. The parts produced by solid modeling can be produced directly by the 3D printing of SDL files to produce the sintered part. The solid part modeling file would be first converted to the inverse mold file and then the mold would be produced by the 3D printing of the SDL files.

The equipment to produce a sintered part is approximately $ 56,000 with the educational discount, but has a rather small build volume of only 40mm x 60mm x 25mm. The equipment to produce the mold to cast the part is approximately $ 100,000 with the educational discount and has a build volume of 250mm x 200mm x 200mm. The equipment for large production molds is approximately $ 1.5 million and is used in several automotive and defense research laboratories.

Conclusions

Rapid manufacturing has advanced the metal casting process to new levels and has greatly reduced the tooling and labor requirements. Rapid manufacturing is revitalizing the metal casting industry in the developed nations by making it more competitive on a cost basis and more appealing to engineers of the future. The new technology will reduce many of the problems of the traditional metal casting industry such as getting skilled molders, patternmakers, and tool and die makers, eliminating the storage requirements for tooling, and reducing the long lead times necessary to obtain traditional tooling. Although rapid manufacturing will require higher skilled computer based designers and programmers and create a cleaner work environment, it will make metal casting more attractive to the manufacturing and production engineers. The manufacturing and industrial engineers of the future must be prepared to implement rapid manufacturing processes to maintain a competitive manufacturing base.

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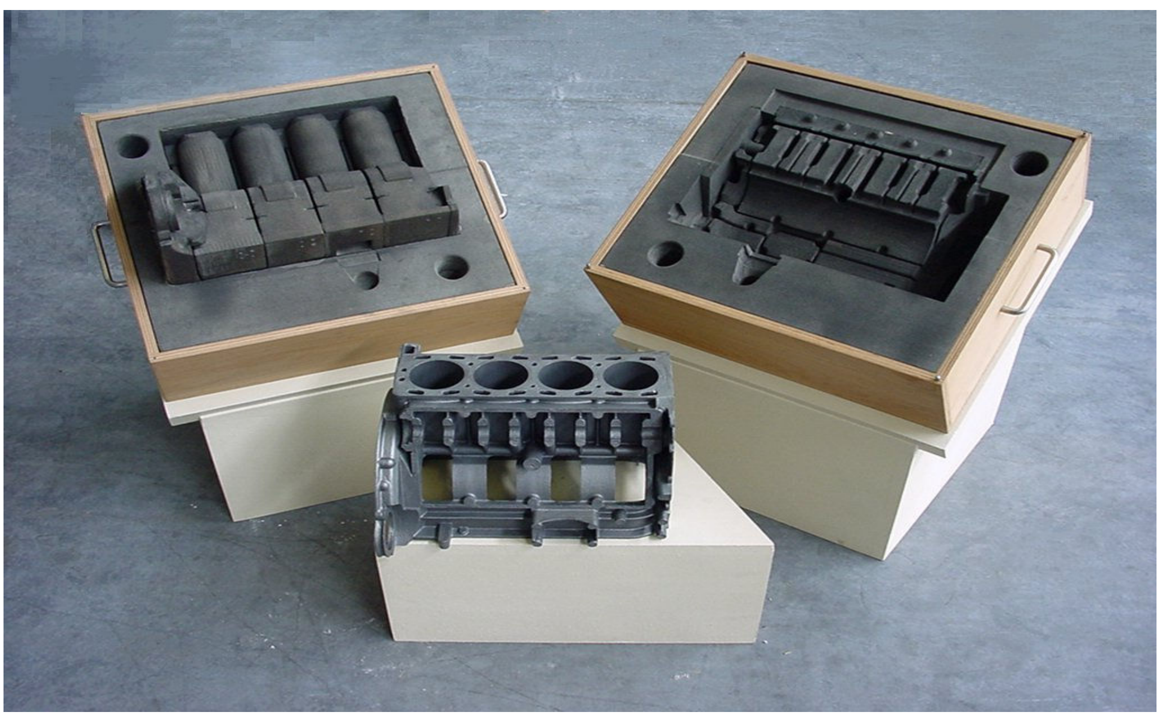

Figure 1. Drag and Cores for Intake Manifold of V-8 Engine (Courtesy of ProMetal, a division of the Ex One Corporation)

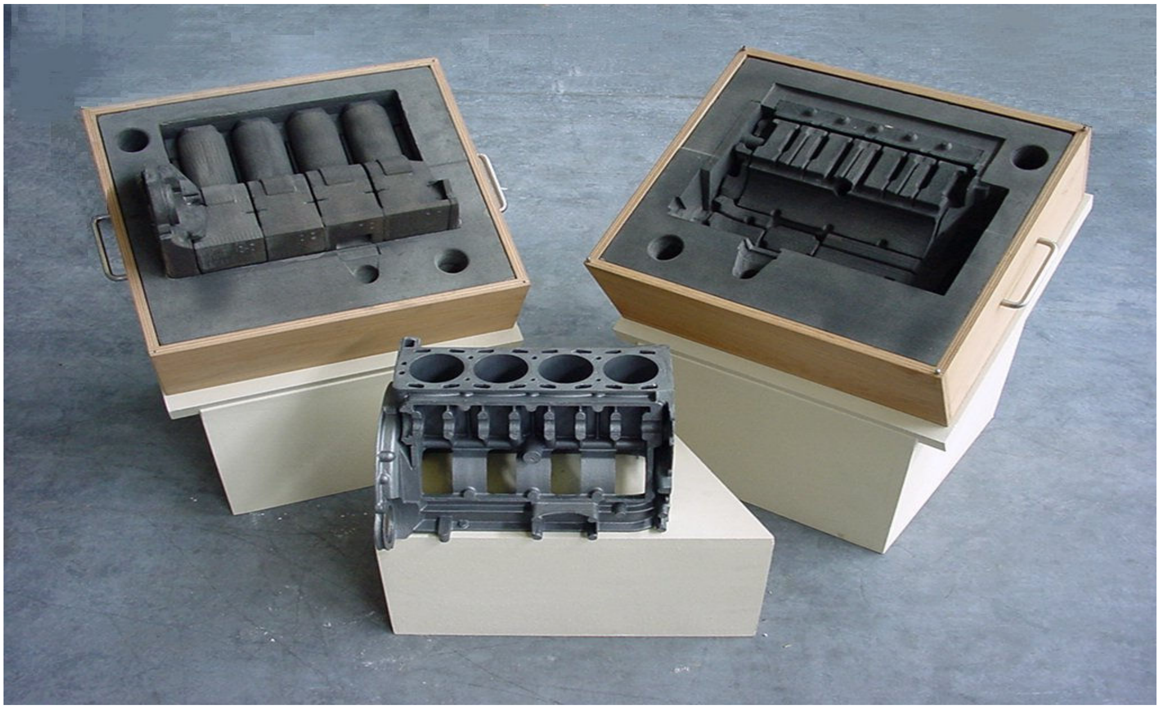

Figure 2. Drag and Cores for Engine Block and Finished Engine Block (Courtesy of ProMetal, a division of the Ex One Corporation)

Figure 3. Core and Mold Parts Made Simultaneously in a Single Cavity (Courtesy of ProMetal, a division of the Ex One Corporation)