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Feasibility Study of manufacturing using rapid prototyping: FDM Approach

Pranjal Jain[a,*], A. M. Kuthe[b]

[a]*Indian Institute of Technology, IIT Mandi, Himachal Pradesh, 175001, India*
[b]*Visvesvaraya National Institute of Technology VNIT, Mechanical Engineering Department, South Ambazari Road, Nagpur, Maharashtra, 440010, India*

Abstract

The objective of this work is to bring about a revolution in Manufacturing Industry from Mass-Production Manufacturing to Tailor-Made Manufacturing in which products are manufactured according to the whims of the customer. For that, Rapid Prototyping (RP) method was used for making a prototype or pattern for casting a product. A new method for investment casting was found out using RP: Fused Deposition Modeling (FDM). RP parts were also tested for using them as a pattern for sand casting. Software named "AUTOCAST-X" was used for designing and simulating zero defect casting. A case study of a middle disc of Oldham coupling was done, in which the disc was produced using both the new investment casting and the sand casting and the parts made by both the methods were compared. Views of foundry personnel were recorded on using RP Patterns in sand casting. They found it very helpful in case of intricate and complicated pattern designs which cannot be made by a pattern maker in wood or metal.

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Keywords: Tailor-Made-Manufacturing; AUTOCAST-X; Rapid Prototyping; Fused Deposition Modeling

* Corresponding author. *E-mail address:* pranjal_jain@students.iitmandi.ac.in

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1. Introduction

Prototypes are very important for realization of concepts in design, manufacturing and analysis. Prototyping is an essential part of product development and manufacturing cycle required for assessing the form, fit and functionality of a design before a significant investment is made (Pham and Gault, 1998).

Nomenclature

FDM	Fused Deposition Modelling
ABS	Acrylonitrile-Butadiene-Styrene
RP	Rapid Prototyping

Presently, a dominant technology for producing physical models for testing and evaluation purposes has been rapid prototyping (RP). CNC prototyping has its own limitations involving the geometric errors due to machine tool accuracy and inaccuracy of machining and thermal errors arise due to frictional forces between the tool and the job (Kosinar and Kuric 2011). Other disadvantages includes the loss of the raw material as the process is subtractive, the fixtures required in CNC machining have their different complicated designs for different types of parts, increased costing due to manufacturing of valves and fixtures themselves, tedious programming associated with the CNC's and hiring skilled labor for overviewing the process that adds to its cost (Lennings, 2000). Also the CNC machines are unable to manufacture parts with non-linear geometry or parts having complicated interiors. That's where RP comes, introduced in the late 1980's, are now established method of reducing work done on product development and its cost and lead times. Considering mass production CNC prototype may be cheaper but for manufacturing a single intricate product, RP prototype would have an upper hand.

The rapid prototyping processes can be broadly classified into processes that uses laser and ones which does not. The laser based processes requires high level of care and maintenance and the machinery is very costly as compared to non-laser based processes. Fused Deposition Modeling (FDM) is second most widely used rapid prototyping technology, after Stereo-lithography (uses laser). In FDM a plastic filament is unwound from a coil and supplies material to an extrusion nozzle which moves over the table in the required geometry and deposits a thin bead of extruded plastic to form each layer of the required geometry. Several materials are available for the process including Acrylonitrile-Butadiene-Styrene (ABS) and investment casting wax. ABS offers good strength, and more recently polycarbonate and poly (phenyl) sulfonic materials have been introduced which extend the capabilities of the method further in terms of strength and temperature range (Dyrbuś, 2010). The most important mechanical properties of ABS are impact resistance and toughness which has tensile strength of 22MPa and tensile modulus of 1,627MPa. Also the flexural strength of ABS is 41MPa and flexural modulus of 1,834MPa with IZOD Impact strength of 340 J/m. It also resists heat successfully with its glass transition temperature of 104 degree Celsius and heat deflection temperature of 96 degree Celsius. Support structures are fabricated for overhanging geometries and are later removed by breaking them away from the object. A water soluble support material which can simply be washed away is also available (Gouldsen and Blake, 1998).

A high level of intricacy can be obtained by this method depending upon the thickness of the layers with dimensional tolerances of +/-0.005" for the first inch and +/-0.002" for each additional inch. In the z-height (vertical), standard tolerances of +/-0.01" for the first inch and +/-0.002" on every inch thereafter are observed. The standard resolution: 0.01"; Minimum wall thickness is 0.02" (Dyrbuś, 2010). On making intricate parts we should not only think about the intricacies in design and shape but also about different sections including thinner ones which are more vulnerable to failure due to resilience and capacity to sustain other natural and manual forces including thermal forces. The advantage of FDM is that the material has good capacity to handle heat and other demanding product tests. It is a feasible option for both rapid prototyping and rapid manufacturing which means manufacturing using RP and producing parts that are both accurate and durable (Gouldsen and Blake, 1998).

FDM is mostly used for project and research work because other RP methods that uses laser technology are costlier and requires very high maintenance that adds up to its cost. One of the other most important reasons that

we used FDM method of RP is because we were equipped with FDM in our CAD/CAM center as it is a non-laser based system, easy to maintain and cheaper than other laser techniques.

2. Rapid Prototyped Sand Casting

2.1. RP Prototyped Sand Casting

The RP pattern made can be used as a pattern in sand casting. It is useful when the shape of the parts is intricate, when metal or wooden pattern cannot be made. For example, a pattern of Funnel shown in the Figure 1 has a peculiar shape and contours which are not only thin but complex and difficult to be crafted on wood as the sections are thin. Also the pattern cannot be made by metal due to its peculiar shape. Therefore a RP part is made which can be then further used to create a master pattern, usually made from aluminium, for sand casting. Another example can be taken when the pattern needs to incorporate core prints within the pattern which are sometimes delicate and small. This could be problematic while using the wooden patterns as it might not be possible to create them in wood due to their tiny shape and neither in metal as it may require extreme precision. Therefore, again the RP method can be used to create the Core Prints in the RP part easily. Medical parts that are used for implant are very good examples of the intricate and delicate parts that are to be casted and RP method are very useful in those cases (Ingole et al. 2009).

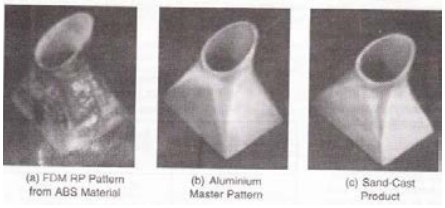

Figure 1. Funnel (RP Pattern, Master Pattern & Sand Cast Product)

The problems in directly using the RP pattern in sand casting includes the hardness and strength of the RP pattern that is less as compared to the metal and wooden patterns, the surface that sticks to the green sand and cause problems like breaking of the walls while removing the pattern after ramming or taking some of the sand with it on the surface of the patterns. Some other ways to get rid of the problem are –

- The first is to obtain the mold cavity using the RP processes and spraying a layer of metal on the mold obtained by RP process. The metal layer forms the mold surface.
- The second is to use the RP process to directly build pattern for investment casting and sand casting process.
- The third is to use the RP patterns for obtaining the master patterns from metals. These metallic master patterns can further be used to make the molds. This may be called as indirect tooling (Ingole et al. 2009).

2.2. Case Study of the middle disc of Oldham Coupling

A case study of the middle disc of Oldham coupling (70mm diameter, 18mm thick) was done by sand casting and the RP pattern was used to check the feasibility of using it in sand casting. Conventional sand casting was done using RP pattern (Figure 2). In the first try, the pattern was stuck to the green sand but then a layer of granite paste was applied over the ABS pattern and after it dried, the process of mould making was done successfully. After that the gating systems and feeders were made as per the simulation done in AUTOCAST-X and pouring was done. Then the cast was then sent for finishing and the finished product can be seen in Figure 3.

Figure 2. Pattern (left) and Cast Product (Right) for Sand Casting

Figure 3. CAD Model for case study

2.3. Usage of Simulation Software

To design the overall casting design of a part, a simulation and optimization software (AUTOCAST-X) was used. It finds the whereabouts of the hotspots in the parts and helps in placing risers and gating system in an optimized way and with optimized dimensions.

3. Using Rapid Prototyping for Investment Casting

3.1. Lost wax vs. Lost RP part

This new process of investment casting (Lost RP Part Casting) is totally different and a lot easier than the conventional investment casting (Lost Wax Casting). It does not require any 'die' to make any wax patterns, neither the process of 'Pattern Assembly' is required here. The problematic work of consecutive dipping of the pattern assembly to make a thick ceramic shell is also avoided by using this process. Actually in this process, the RP part itself is used as a pattern instead of a wax pattern which is then further used for casting the metallic part (Kosinar and Kuric 2011). The most important advantage is that the method has been successful in getting rid of the cores. Designing cores and placing them in the mould-box are one of the most difficult tasks and requires much greater accuracy (Frank et al. 2003). Therefore, this new type of investment casting has done away with all the problems that needed to be faced while dealing with cores. Unlike conventional investment casting, where the gating system and the feeders are attached externally to the pattern, the RP pattern here incorporates the gating system and feeders. The RP pattern used for sand casting and investment casing is different in the fact that the RP used for sand casting does not have the gating system and feeders and is just a model of a finished product.

Table 1. Comparison of Patterns made from FDM ABS and Wax from Tooling. (Gouldsen and Blake, 1998).

SR. NO.	ABS Pattern Made by RP:FDM	Wax Pattern
1.	Parts are strong and able to withstand rough handling.	Delicate and Fragile but good surface finish.
2.	Thin-walled parts can be created without fear of breakage.	Consistency of dimensions but difficult to create thin-walled parts.
3.	Only a few foundries, at this time, are using ABS patterns.	Used mostly in many foundries.
4.	Requires high one time investment in the RP Machine to achieve low tooling cost.	High tooling cost but large quantities can be produced economically.
5.	Pattern can be created comparatively faster.	Long lead times of up to 12 weeks.

3.2. Usage of Simulation Software

Actually the software is designed to contrive sand casting, but we can also use the data provided by the software in investment casting. By designing the gating system and feeders in the software, we know where to incorporate them for best results in both investment and sand casting, but the difference is that we have to incorporate the same in the RP pattern in case of investment casting. Firstly, a CAD model of the part that needs to be manufactured is made using any CAD software. Then it is converted into a .stl file by saving it in that format. After that the file is opened in AUTOCAST-X and designing of the systems and then optimization is done for the best. A report is created by the software documenting all the necessary details including the dimensions of various parts etc. Now to incorporate the gating system and feeders we open the existing CAD file and with the help of the report and the dimensions given in the report we design the gating, runners, sprue, pouring basin, sprue well and feeders in that CAD software itself and convert it into a .stl file. Hence we make a modified pattern that can be used for investment casting while also using the information from the software.

The features which are absent in AUTOCAST-X that are required in case of investment casting are:

- Directly saving the modified part in .stl format or any CAD format.
- The data about the material used and costing is present only for sand casting only.

3.3 Case Study of the middle disc of Oldham Coupling

A case study of the same middle disc of Oldham coupling is done and the whole process is illustrated in Figures 3 to 9.

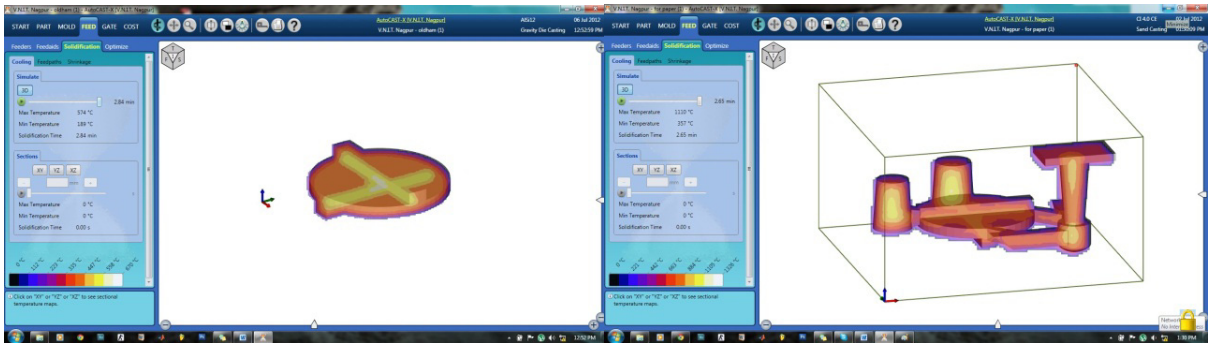

Figure 4. Checking the hotspots (left) and solidification after designing the casting process (right)

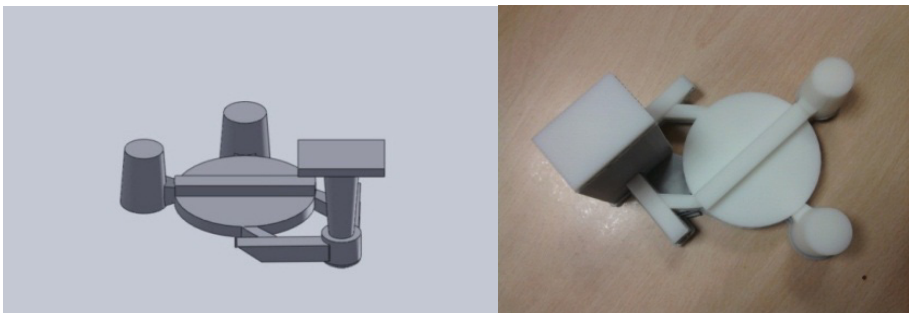

Figure 5. CAD Model of modified Pattern (left), Pattern for Investment Casting (right)

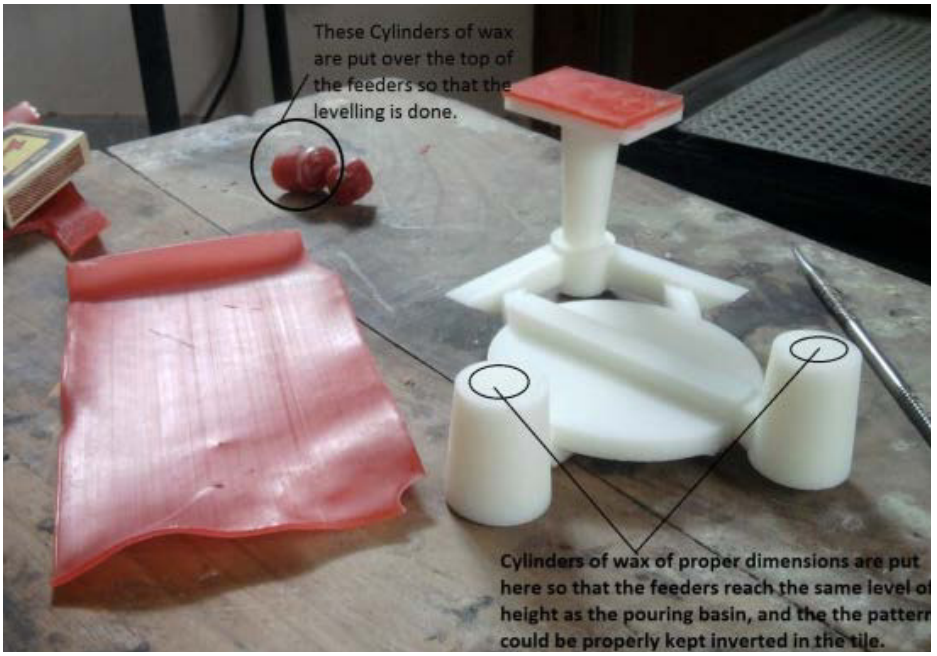

Figure 6. Balancing heights of pouring basin and risers with wax

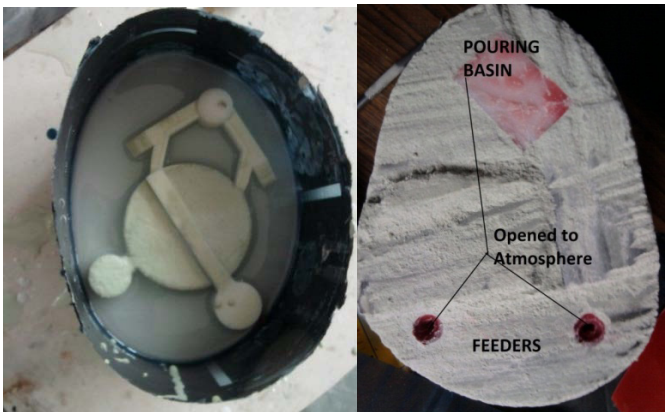

Figure 7. Mould Preparation

Figure 8. Stepwise baking

Figure 9. Pouring and then breaking the mould (left); Finished Cast using new Investment Casting (right)

4. Costing

The comparison of costing of the sand and investment casting is made by the following cast studies of the middle disc of Oldham coupling. The following are the deductions made from of costing of both sand and investment casting (for one part) –

The tooling cost is more in case of sand casting due to extra defects like sand particles inclusions in the surface and more errors in dimensional allowances whereas we get mores surface finishing in case of investment casting. The Cast metal Cost of the sand and the investment casting are nearly same because Cast metal costing depends on the dimensions of the casts prepared which are same in both the cases. The tooling cost is lower in case of investment casting as the surface is smoother in this case because the sand particles does not stuck to the surface of the metal part which is a problem in sand casting sometimes.

The total material costing in investment casting is much greater than that of sand casting due to the material used to make the slurry and the wax that is used in case of investment casting which is too costly as compared to Green Sand in case of sand casting. Also the pattern is a onetime investment in sand casting unlike investment casting.

We had not evaluated the energy and labor cost but we can say that the energy cost may be high for the investment casting as the RP part needs to be baked on muffle furnace that works on electricity and consumes lot of it. Also the RP pattern for investment casting consumes more electricity due to its bigger size than sand casting. We can also guess about the labor work which may be high for Sand casting as extra labor is required for making mold and preparing sand and proper ramming of the sand. Labor for pouring and other petty works are common for both.

Total cost for sand casting is much lower than that of investment casting but the ease of doing the process, the finishing of the cast and to get the cast of least defects one has to follow the process of investment casting. To get Zero-Defect-Casting at one go one has to use the process of investment casting.

5. Conclusions

RP pattern can be used in sand casting when pattern making is troublesome meaning that the design of the pattern is complicated which is not possible to make in wooden or metallic forms. They can be successfully used in mass production after making a metallic master pattern usually made of aluminum or by spraying layers of metal over the pattern (Pham and Gault, 1998).

When we talk of tailor made products which are made as described by the customer as per his descriptions, one cannot afford to do experiments with the casting systems as we do in case of mass productions but one has to do it in one go. In this scenario, investment casting by lost RP part comes into picture where there is no room for faults, the simulation and the casting design is already done in the software and one has to follow the design as mentioned by the software report and the process suggested by us. Also parts which are intricate in shape and are required in

small quantity the same process can be utilized where there is no tension of core or cope and drag or ramming of sand where there is a chance that the pattern might be damaged.

Incorporating vent holes in the mold in the new process of investment casting, which are thought to play an important role in the process of casting, might be difficult. This might cause some problems in aeration and venting of gases.

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