Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 1, Number 1; October, 2014 pp. 10-13

http://www.krishisanskriti.org/jbaer.html

Additive Manufacturing Technique in Pattern making for Metal Casting using Fused Filament Fabrication Printer

Cany Mendonsa[1], Vyas Darshan Shenoy[2]

[1]*Mechanical Engineering, Manipal Institute of Technology, canyalwyn12@gmail.com*
[2]*Mechanical Engineering, Manipal Institute of Technology, vyasdarshan_shenoy@yahoo.co.in*

Abstract: **Conventional pattern manufacturing for prototyping can take more lead time to manufacture and sometimes prove to be expensive. This paper presents two methods of implementing additive manufacturing using Fused Filament fabrication printer in conventional pattern manufacturing for metal casting using polylactic acid investment methods, and 3D printed pattern and core models for cope and drag. In the polylactic acid investment method the investment containing 3D printed polylactic acid pattern produced by fused filament fabrication printer which when heated above its melting temperature (180 □ C) burns out leaving a cavity which will be further used for casting metals . In a 3D printed pattern, core is printed, based on actual 3D CAD model using fused filament fabrication printer for the cope and drag .These two methods can be implemented for casting metals using fused filament fabrication printer rather than expensive metal 3D printers for small scale foundries.**

1. INTRODUCTION

Fused filament fabricator (FFF) printer is a machine which uses heat to melt the polymer material extruded through its nozzle just at its plastic state, 180 to 200°C for PLA and 230 to 240°C for ABS which deposits on the printer bed with synchronous movement of the XYZ coordinates of the machine which creates a 3D object layer by layer modeling as per 3D designed model using modeling software.

Pattern making is a critical activity in foundry. Patterns made out of wood or metal may sometimes prove to be costly and time consuming since making a complex pattern out of wood may take more lead time and complex shapes sometimes prove to be difficult. This paper presents methods in which additive manufacturing technology can be used to produce complex patterns in a short time using polymer patterns printed out in FFF printer.

2. PATTERN MATERIALS

2.1 Materials Used For Pattern

2.1.1 Poly Lactic Acid

Poly lactic acid (PLA) is biodegradable thermoplastic aliphatic polyester with molecular formula $(C_3H_4O_2)_n$ derived from renewable resources, such as corn starch, tapioca roots or sugarcane[1]. Fig.1 shows grain structure of PLA filament under metallurgical microscope.

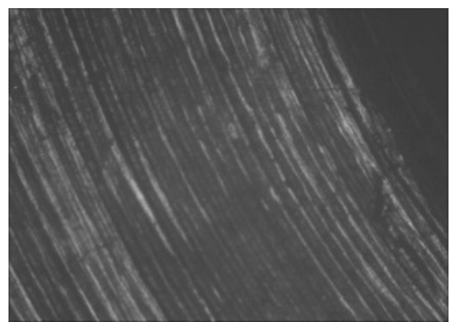


Figure 1. Grain structure of PLA

PLA is most suited for investment method due to its low melting point temperature with glass transition temperature of 60–65 °C and does not produces hazardous toxics such as produced by ABS.

2.1.2Acrylonitrile Butadiene Styrene

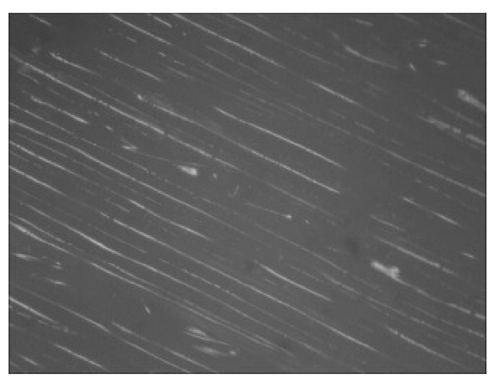


Figure 2. Grain structure of ABS

Acrylonitrile butadiene styrene (ABS) with molecular formula $(C_8H_8{\cdot}C_4H_6{\cdot}C_3H_3N)_n$ is a common thermoplastic having transition temperature of approximately 105 °C [2]. ABS is amorphous and therefore has no true melting point. Fig.2

shows grain structure of ABS filament under metallurgical microscope.

ABS is a polymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene and its proportions may vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. For the majority of applications, ABS can be used between −20 and 80 °C as its mechanical properties vary with temperature[3].

2.2 Comparison between PLA and ABS

There are many materials that are being explored for 3D printing, however the two dominant plastics PLA and ABS are known as thermoplastics when they are heated to transition state they become soft and moldable and return to solid state when cooled. Their ability to melt and be processed again is what has made them so prevalent in society and is why most of the plastics in use with on a daily basis are thermoplastics.

Now while there are many thermoplastics, very few which are currently used for 3D printing. The material to prove viable for 3D printing, it should undergo three different tests; initial extrusion into plastic filament, second binding during the 3D printing process and finally end use application.

2.2.1 Storage

Both PLA and ABS do best if, before use or when stored long time, they are sealed off from the atmosphere to prevent the absorption of moisture from the air.

PLA responds somewhat differently to moisture, apart from bubbles or spurting at the nozzle, it may have discoloration and a reduction in 3D printed part properties as PLA can react with water at high temperatures and undergo de-polymerization. PLA can also be dried using simple instrument such as a food dehydrator, it is important that this can alter the crystalline ratio in the PLA and will possibly lead to changes in extrusion temperature and other extrusion characteristics. For most 3D Printers, this need not be of much concern.

ABS - Moisture laden ABS will tend to bubble and spurt from the tip of the nozzle while printing, reducing the visual quality of the part, strength, part accuracy and introducing the risk of stripping or clogging in the nozzle. It can be easily dried using a source of hot air such as a food dehydrator.

2.2.2Part Accuracy

Both PLA and ABS are capable of creating dimensionally accurate parts. However, there are a few points to mention regarding the two in this regard.

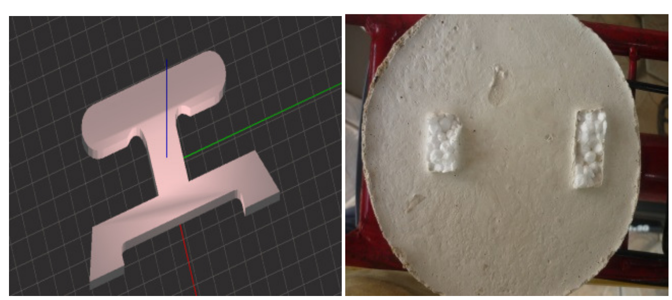
PLA demonstrates much less part warping and it is possible to successfully print without a heated bed and use more commonly available "Blue" painters tape as a print surface. Ironically, complete removal of the heated bed can still allow the plastic to curl up slightly on large parts, but not always. PLA undergoes more of a phase-change when heated and liquefies. If actively cooled, much sharper details can be seen on printed corners without the risk of cracking or warping. The increase in flow can also lead to stronger binding between layers, hence improving the strength of the printed part.

For most, the single greatest hurdle for accurate parts in ABS will be a curling upwards of the surface in direct contact with the 3D Printer's print bed. A combined process of heating the print surface and ensuring it is smooth, flat and clean take long way in eliminating this issue. Moreover, some find various solutions that can be useful when applied beforehand to the print surface. For fine features on parts involving sharp corners like gears, there will often be a slight rounding of the corner. The fan can provide a small amount of active cooling around the nozzle can improve corners but one does also run the risk of introducing too much cooling and reducing adhesion between layers lead to generate crack in finished part.

3. METHODS USED FOR CASTING METALS USING 3D PRINTED PATTERNS

3.1 Polylactic acid investment casting

The 3D pattern is printed as per the 3D CAD model, as shown in fig.3 (a), Fig.6 the printing is made at 100 micron layer to get smooth surface finish, and the 3D printed model is finished by removing the support materials used for printing. The investment is prepared using 4:3 parts of Plaster of Paris and sand with three parts of water creating a dense mixture Fig.3(b). 3D printed model is submerged into the investment leaving the investment to solidify. The investment is preheated in the muffler furnace for one hour at 200-230°C where water content in the investment evaporates leaving the dry investment. The investment is further maintained to 600°C for one and half hour until the plastic burns and vaporizes leaving behind cavity Fig.3(c) in the investment which will be further processed in moulding box during pouring of molten metal in order to prevent the breaking of investment due to high temperature of the metal Fig.3(d).



(a) **(b)**

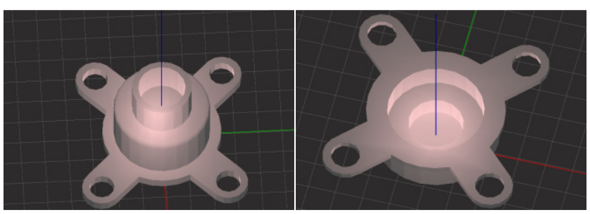
(c) (d)

Figure 3. (a) 3D CAD design of the model (b) Casting investment. (c) Cavity obtained and (d) investment inside the green sand for support

Figure 4. Casting obtained using PLA investment.

3.2 Patterns

The patterns are produced using PLA and ABS material in the 3D printer as per CAD model for cope and Drag.



(a) (b)

Figure 5. (a) & (b) 3D printed patterns

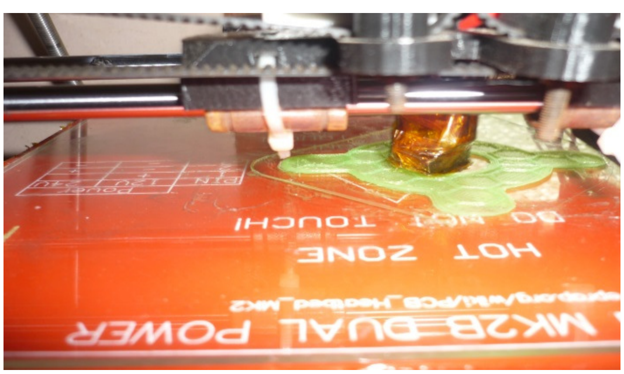
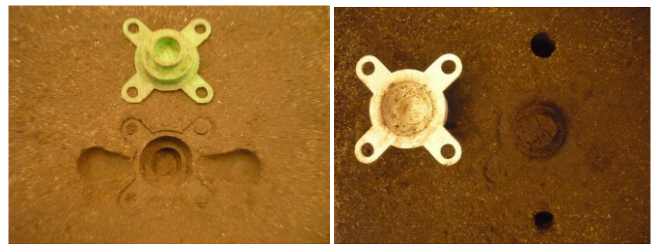


Figure6. 3D model printing using FFF printer.

The cope and drag are made separately taking into consideration the center line of the drag having one part of 3D printed pattern matches with the center line of the cope hence avoiding miss match while casting. After the patters are printed the support materials for the over hangs from the printed pattern is removed. Pattern as shown in figure (a) is placed in the drag and pattern shown in figure (b) is placed separately in drag and cope and rammed. Patterns are removed from drag and cope leaving behind the cavity in it.

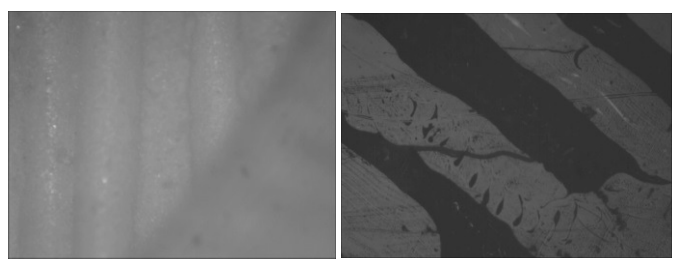


(a) **(b)**

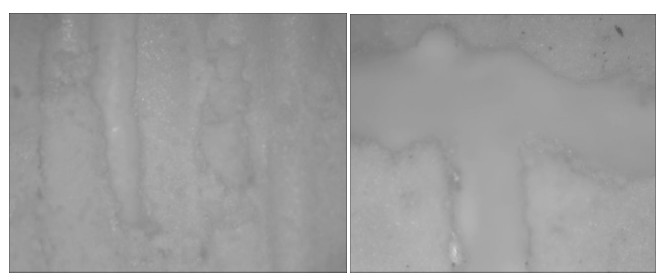
(c)

Figure 7. (a), (b) & (c) Cavity obtained in drag and cope.

4. DEFECTS CAUSED BY THE FFF PRINTER



(a) (b)



(c) (d)

Figure 8. (a) & (b) Surface defects with internal crack. (c) & (d) surface crack in investment due to low sand content.

Fig.8 (a) and shows the deposition of investment in to the layer of 3D printed object due to errors caused by the FFF printer which leads to decrease in surface finish of the object.

Fig.8 (b) and shows the grain structure of the 3D printed PLA model where the dark area represents the offset between two print layers having approximately 20 micron depth and width and Fig.8(c) the deposition of the investments in the offset layer of the printed pattern creating surface defects.

5. CONCLUSION

TWO METHODS, of implementing additive manufacturing in conventional pattern manufacturing used for metal casting using PLA investment method and 3D printed pattern for cope and drag are successfully performed. Both lead time for manufacturing and the cost are reduced drastically by these methods. Complex shapes can also be obtained easily with higher accuracy and better surface finish.

6. ACKNOWLEDGMENT

We would like to thank Dr. Divakar Shetty, Dr. S.S.Sharma and Dr. Achutha Kini for their valuable support and guidance in carrying out this research project. Also we like to thank our parents for all their valuable support.

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