Investigation on Mechanical Properties of 3D Printed PLA Pattern for Sand Casting Application

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Abstract - *3D printing patterns has been proposed as an alternative for pattern production; however it has not been widely adopted as a popular alternative to conventional/traditional casting techniques. The purpose of using this rapid prototyping method is to prevent material waste in pattern creation while also lowering costs and improving time management. CNC machined patterns are used in the traditional way of creating castings with materials such as metals. CNC prototype has its own limitations, including geometric mistakes induced by machine tool precision and thermal inaccuracies generated by frictional forces between the tool and the work piece. This work is to enlighten the foundry engineers to make use of rapid prototyping technology to eliminate the material wastage in pattern production, reduce the cost and time in the production of accuracy casting of an acceptable quality. The present work is to replace a wooden pattern with a 3 D printed pattern for which a simple split pattern is designed and taken into consideration for fabrication in rapid prototyping process which thereby used in aluminium sand casting. Further investigated mechanical properties of PLA, prepared the samples as per the ASTM standard conducted experiments and compared with wooden pattern. PLA pattern materials showed good mechanical properties then wood materials for pattern.*

Key Words: Complex Patterns, Rapid Prototyping, 3D Printed pattern, Sand casting FMD macine.PLA.

1. INTRODUCTION

3D printers have become affordable to the dedicated home user. In fact, many high-quality 3D printers cost less than $3000, including dual extruders and a heated build surface [1]. Many of these consumer-level 3D printers are advertised as printers that use the Polylactic Acid (PLA) material rather than the more typical, but more difficult to print with, Acrylonitrile Butadiene Styrene (ABS). PLA is stronger than ABS, but it's less durable. PLA has a reduced coefficient of thermal expansion, which mitigates the impacts of warping, non-adherence to the printed surface, and big sections splitting during printing. PLA also does not provide the same health dangers as ABS when printed in poorly ventilated environments [2]. The most obvious downside of PLA is its low deflection temperature under load (50 to 140°C), which causes printed items to distort when exposed to heated environments. One kilograms spools of either material cost approximately $50 (in early 2014) [1]. With this entire in mind, it's simple to see why many 3D printer makers are creating and supporting 3D printers that only use PLA

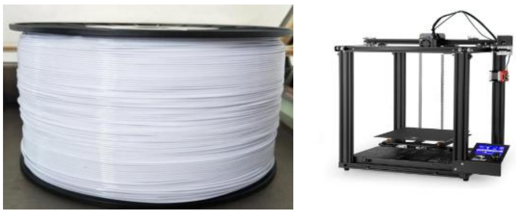
Many people are already printing in PLA at home using personal 3D printers, and many more will do so shortly. MakerBot alone has sold over 15,000 3D printers over the last five years [3]. ABS material qualities and features have been extensively investigated, with numerous experiments testing print orientations [4-9]. Most of these investigations were conducted on "professional" type machines. Consumer machines' print quality for ABS has been mostly untested, and literature addressing material property features of 3D-printed PLA could not be discovered.

The purpose of this study is to gain an understanding of the behaviour of 3D-printed PLA using a consumer-level 3D printer. Specimens were printed to evaluate tensile strength, flexural strength, and fatigue, and the filament was also tensile tested. By default, if the Maker Ware software, used by the MakerBot line of 3D printers, is instructed to produce a specimen/object at 100% infill, the slicing programme will print in alternate raster orientations, layer by layer. A bespoke printing profile was created for each specimen to print totally in a single raster orientation in order to investigate the relationship between printing orientation and material distortion.

2. EXPERIMENTAL PROCEDURES

Several forms of mechanical property tests were performed on PLA filament and PLA 3D-printed specimens. The CUBE-XR33, a consumer 3D printer, was used to print all of the specimens. The slicing/printing software was controlled by custom printing profiles, which allowed for printing in a single set raster orientation for the entire specimen. To make all specimens as comparable as feasible, each specimen was printed individually in the centre of the printing bed. All specimens had two "shells" around the periphery, and the inside was printed with 100% infill density at specific raster orientations. The PLA material was extruded at 240°C at a speed of 15mm/sec, with the heated bed surface set to 65°C, layer resolution of 70-300 microns, a nozzle diameter of

0.4mm, and filament diameter of 1.75mm. Each specimen was printed with the same generic brand of PLA filament from 1-kg spools purchased together.



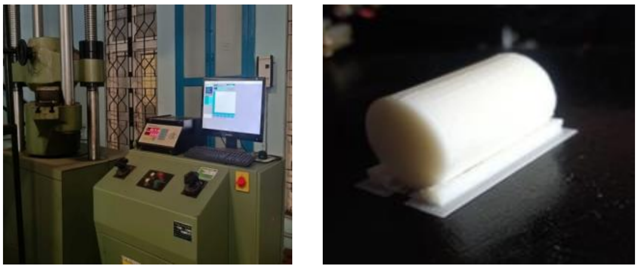
(a) (b)

Figure: 1 shows the used PLA Filament with 1.75mm diameter and FDM Machine.

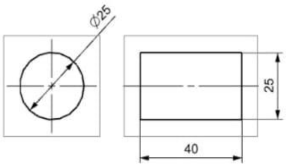
Individual specimens were measured (thickness and width) at various points during the test section. The ASTMs employed the smallest cross sectional area (or the cross sectional area at the centre of the beam for specimens for compression testing) to calculate appropriate stress levels. MTS universal loading machines were used to perform the compression testing. Compression testing of the 3D-printed object was conducted using MTS 100kN load cells. Compressions testing of the PLA filament used in the UTM Machine, built-in LVDTs were utilized to monitor displacement, and an MTS extensometer with a gauge length of 20mm was used to measure strain for the compression testing of the 3D-printed specimen, as well as an impact and hardness test. All experiments were carried out at ambient temperature (about 28°C).

2.1 Compression Testing

The specimens were examined in accordance with the ASTM D695 standard, which specifies compression test techniques for plastics. The MTS wedge grips were shifted at a rate of 5 mm/min, while data (force, grip displacement, and strain) were recorded at 100 Hz. An MTS extensometer (20 mm gauge length) was utilised to measure strain. Figure 2 shows the testing setup for Compression testing of the 3d-printed specimen. Figure 3 shows the geometry of the specimen used for compression testing with dimensions of 40x25mm. Specimen is tested under the UTM (Universal Testing Machine).



(a) (b)



(c)

Figure: 2 (a) Universal Testing Machine (Compression test) (b) prepared specimen for compression test (c) Sample dimensions.

The following procedures has been carried out for conducting the compression test .Set the load dial of the machine to a suitable range and adjust the testing machine and compressometer to read zero. Apply load at slow speed and make simultaneous observations of load and strain record the deformation with respect to load and note down yield point and maximum load observe the location , character of the fracture and measure the final diameter , length and finally determined the compressive strength by using formula max load by original cross section of sample.

$$MAX.\frac{COMPRESIIVELOAD}{AREA} \qquad (1)$$

2.2 Rockwell hardness testing

Specimen were tested according to ASTM D883 standard test method for properties of plastics .The Rockwell hardness number represents the maximum possible remaining travel of a short stroke machine from the net depth of impression, as the load on the indentor is increased from a fixed minor load to a major load. Indentor is round steel ball of specific diameter (2.5mm) and specimen dimensions has been taken 8x20mm (thickness x diameter).

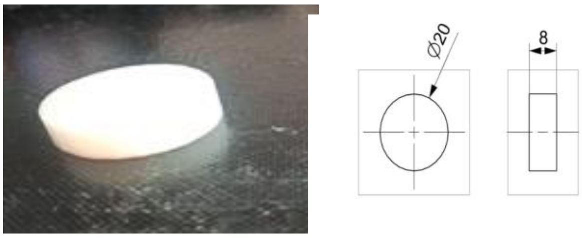
(a) (b) (c)

Figure: 3(a) Rockwell Hardness testing machine (b) prepared sample (c) sample dimensions

The following Procedure has been adopted for conducting the Rockwell hardness testing. Specimen has been placed on the anvil surface was normal to the direction of the applied load. Then ball type indentor has been selected (2.5mm). The small pointer in the dial starts to move and touches the indentor. Then (60kgf) was applied upon the specimen until the dial reaches the zero point. The load was applied for 10sec there after values were recorded.

2.3 Brinell hardness Test

Brinell hardness is usually defined as the resistance to permanent indention. Hardness test consist in measuring the resistance to plastic deformation of layers of poly lactic acid near the surface of the specimen. In process of hardness determination when the metal is intended by a special tip (ball Indentor), the tip first over comes the resistance of specimen to elastic deformation and then a small amount of plastic deformation.



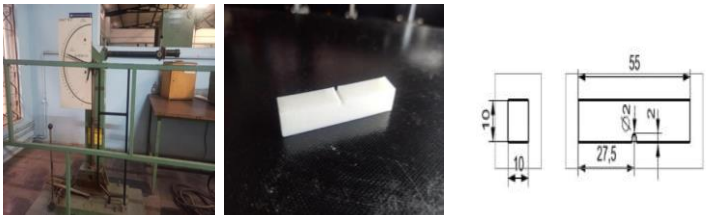
(a) (b)

Figure: 4 (a) prepared sample for Brinell test (b) dimension specimen and 3D model

The following Procedure has been adopted for conducting the Brinell hardness testing. Specimen has been Placed on the anvil surface was normal to the direction of the applied load. Then ball type indentor has been selected (2.5mm). The small pointer in the dial starts to move and touches the Indentor. Then (60.25kgf) was applied upon the specimen until the dial reaches the zero point. The load was applied for 10sec there after values were recorded then substituting values in formula 2P/ΠD (D-√D2-d2) BHN has been determined.

2.4 Impact test (Charpy method)

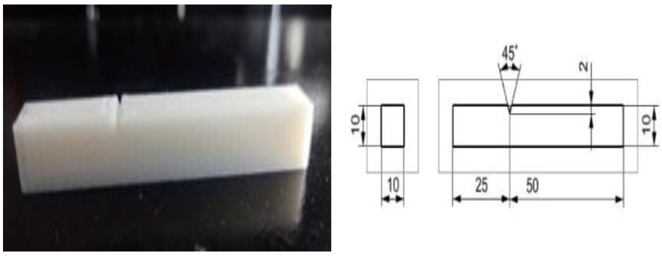
Impact test determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent brittle-ductile transition. It is to determine whether the material is brittle or ductile in nature.



(a) (b) (c)

Figure: 5 Charpy Test machine (b) Prepared sample (c) Sample dimensions

The following procedure has been adopted for conducting impact testing. Charpy/Izod method was conducted on specimen accordance to ASTM D6110 (10x10mm with 2mm depth of notch) set the pendulum to angle 135°/90°and attach V-edge/Point sticker with no specimen in the anvil, swing the pendulum to ensure freedom of movement and note down the friction loss, note the weight W of the pendulum and the radius r of its center of mass. Lift the pendulum to its upper position, and fix the specimen such that notch face is opposite to the striker. Release the pendulum to rupture the specimen and record the energy of the rupture from the scale. Stop the pendulum to Swing by means of the hand break lever and calculate the impact strength by Charpy/Izod method using the formula absorbed energy divided by original cross section. Similarly Izod test was also conducted by adopted the following procedure.



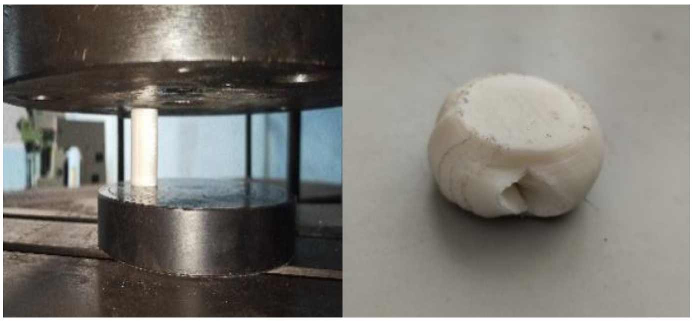
(a) (b)

Figure: 6 (a) Prepared sample for Izod test (b) Dimension of specimen

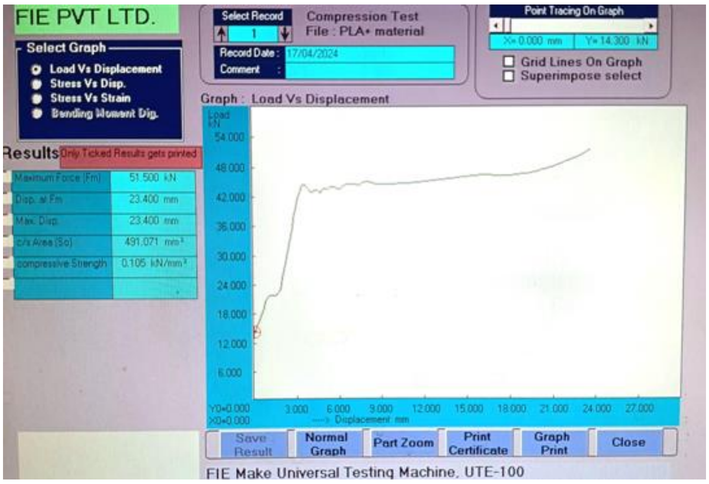
3. RESULTS AND DISCUSSION

3.1 Compression test

The specimen were tested under UTM as per the above said ASTM standard as we absorbed that applied compressive load was along axis of the grains, this was helps to hold the compressive load. After some time length of the grains/sample were decreasing gradually by increasing the compressive load as well. As result cross sectional area of the sample was expanding that leads to take small micro-cracks originates in the samples, this progressively developed the final fracture of the specimen. Figure 6(b) is an evidence of the brittle fracture was noticed. Figure 6(c) an indicated that graphical representation of deformation of Polylactic acid (PLA) which helps to indentify max yield and fracture load the sample. Figure 6 (a) shows that UTM machine with position of sample.



(a) (b)



Compression Test
File : PLA+ material
Record Date : 17/04/2024
Comment :
X= 0.000 mm Y= 14.300 kN

Maximum Force (Fm)	51.500 kN
Disp. at Fm	23.400 mm
Max. Disp.	23.400 mm
c/s Area (So)	491.071 mm²
compressive Strength	0.105 kN/mm²

FIE Make Universal Testing Machine, UTE-100

(c)

Figure: 6(a) Prepared sample for compression test (b) Dimension of specimen (c) Graphical representation of compression test.

Table: 1 Comparison between wood and PLA materials

Sl.No	Compressive strength of materials kN/mm^2			
1	Teak wood	0.0349	PLA (Polylactic acid)	0.105

Table 1 and figure 7 indicates the comparison between existed Teak wood and proposed PLA materials from the experiment we understood that PLA material has compressive strength more than existed teak wood. This is an evidence to strongly recommend PLA materials to prepare the pattern for casting. And cost factor of the PLA is lesser then teak wood, also light in weight.

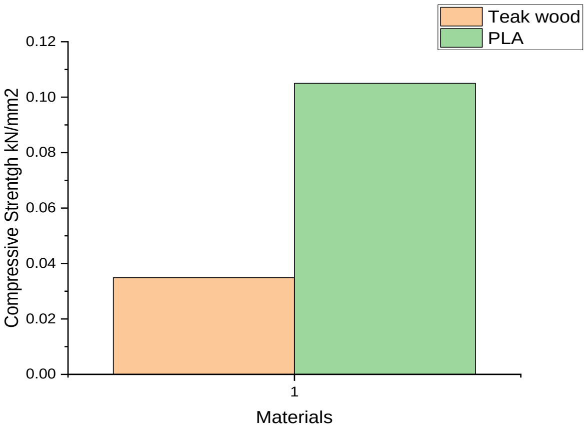


Figure 7 Compressive Strength of Teak wood and PLA materials

3.2 Rockwell Hardness Test/Brinell hardness

Rockwell hardeness test has been carried out as per above said ASTM standard. It is noticed that average value up to 85RHN.Becouse starch blends with natural sugar cane.PLA is stronger and stiffer thermoplastic.

Table: 2 Rockwell hardness values

Sl No	Material	Scale	Indentor	Load in KGF	Rockwell Hardness Number
1.	Poly Lactic acid	Black	Ball (2.5mm)	62.5	**B 85**

The above table 2 shows Rockwell hardness number of PLA by average of three trials and scale, type of load and indentor. Similarly BHN also conducted as per standards. It is shown below table 3.

Table: 3 Brinell hardness values

Sl No	Type of material	Load in KGF	Dia of indenter	**BHN**
1.	Poly lactic acid	62.5	Ball (2.5mm)	**42**

The hardness values are an evidence to understand natural stuff of PLA is stronger than teak wood; PLA would resist the plastic deformation more than teak wood while applying the load on surface of PLA.

3.3 Impact Test

Impact test has been carried out as per the aforesaid ASTM standard samples were fabricated. Values were recorded for

Izod 0.05 J/mm2 and 0.025J/mm2 for Charpy. With this value to recommend for pattern application for sand casting.PLA materials which has natural stuff of starch and sugar cane has possesses hardness nature, which resists transfer of load in to it that clearly indicates on fracture surface which appears brittle fracture with no appreciation in deformation. Figure-7 shows the fracture surface of sample.

Figure: 7 Impact fracture sample

3.3 3D Printed PLA Pattern

(a) (b)

Figure 8 shows that pattern (a) Teak wood pattern and (b) 3D printed PLA pattern

Above figure indicated that casting pattern made up of two different materials figure (a) is made by teak wood and fabricated from traditional way of manufacturing which is already existed in foundry where as in figure (b) is made by PLA (Polylactic acid) fabricated from fused deposing modelling (FDM) 3D machine this is an evidence to understand dimensional accuracy and surface finish of the model. 3D printed model has been proved that it is better than the wood (surface) in above aspects, also light in weight, water resistant, less chemical attraction and biodegradable hence this work proposes replacement of wood pattern to PLA pattern for sand casting

4. CONCLUSION

This work mainly focus on replacing wood pattern to PLA, for that designed pattern then fabricated by PLA, latter work have been extended to evaluate of the mechanical properties of PLA material through various testing methodologies like compressive strength, hardness and Impact properties. Our findings indicate that PLA exhibits promising mechanical characteristics, making it a viable option for a range of pattern for sand casting application, particularly in industries where biodegradability and sustainability are paramount.

Through compression testing, observed that PLA demonstrates satisfactory compression strength compare to teak wood which was already existed and ultimate load suggested it’s suitable for pattern for sand casting application. Furthermore, the Hardness testing revealed PLA’s ability to withstand forces, highlighting its potential for use in pattern for sand casting application

The impact resistance of PLA was evaluated through (Izod & Charpy) impact testing, showcased its resilience to sudden shocks and dynamic loading. This property makes PLA suitable for pattern for sand casting application requiring durability and resistance to impact forces.

Overall we conclude that PLA material has shown the mechanical and physical property stable than wooden material.

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