Evaluating the Mechanical Properties of Commonly Used 3d Printed ABS and PLA Polymers with Multi Layered Polymers

Shabana, R.V.Nikhil Santosh, J.Sarojini, K.Arun Vikram, V.V.K.Lakshmi

Abstract: Rapid prototyping is a technology capable of producing physical models in layer by layer directly from CAD model without any tools, dies and fixtures while involving little human intervention. Rapid prototyping can fabricate complex shapes easily as compared with traditional manufacturing. It also helps in early detection and reduction of design errors. Thermoplastics used in this study are ABS and PLA which are easily available and cost effective. This study aim to investigate the mechanical performance of the 3D printed ABS and PLA thermoplastics and comparing them with the sample produced by preparing the multilayer of those themoplastics. An attempt is made to increase the mechanical performance by preparing the samples with multilayer structures using ABS and PLA. Mechanical tests like Tensile test, Compressive test, Flexural strength, Microhardness and surface roughness have been conducted as per the ASTM standards. Microstructures of the samples are acquired with optical microscope. From the results obtained ABS exhibited more flexural strength and higher elongation before breaking. But ABS consists of chemicals when heated to a certain temperature releases organic volatile compounds which are health hazardous. In order to reduce the chemical effect of ABS, a thermoplastic called PLA is used which is produced naturally and is incorporated to decrease ABS content and achieve the properties of ABS. In the present work the flexural strength of layered sample is nearer to the ABS. So, inorder to reduce the chemical effects of ABS the layered polymer can be used.

Keywords : Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), HIPS, PETG, TPU, 3D printing, Additive Manufacturing.

I. INTRODUCTION

3D printing or additive manufacturing is a manufacturing technology in which objects are produced by adding the material. It is a rapid prototyping process where a actual object can be created from 3D design. A 3D printer uses a CAD (Computer Aided Design) model for rapid prototyping process. The 3D design is stored in as stereo lithography (.STL) format and after that processed to the 3D printer [1]. It uses a wide range of materials such as ABS, PLA, HIPS, PETG, TPU and composites as well. 3D printing is one kind of rapidly developing and cost optimized technology which can be used for rapid prototyping. The 3D printer prints the CAD design layer by layer forming an actual 3D object. In the recent years faster and cheaper Additive Manufacturing techniques have been developed which yield to high quality print. Even the polymer materials used for 3D printing are now being produced with a range of properties. [2-6]These developments persistently vary according to the products designed and manufactured as per their applications. 3D printing has applications in many industries such as architecture, automotive, education, medical, business and consumer industries. In general, plastics have low strength compared to metals, they have higher strains lower density and are at failure. But in some cases, Plastics have higher strength per unit weight than metals. Therefore, considering its cost effectiveness and manufacturability with intricate designs, plastics could have more advantages and many applications. [7] The objective of this research is to evaluate the mechanical performance of ABS and PLA and comparing it when they are multilayered. An attempt was made to improve the mechanical properties using the multilayered approach. ABS is a commonly used thermoplastic. It is widely used in FDM printers. ABS has tough, stiff, chemical, moisture and heat resistant properties but its major drawbacks are its non-biodegradability and higher emission of Volatile Organic Compounds (VOC). PLA is a biopolymer prepared from corn, sugarcane. And it has good mechanical properties, low toxicity, and good barrier properties. Its major drawbacks include brittleness and low thermal stability. [8-9]. To reduce the effects of VOC in ABS some multiple layers of PLA were incorporated, and a new specimen was obtained which had only 50% ABS. The mechanical properties of the multi-layered specimen were tested and compared with ABS and PLA.

II. EXPERIMENTATION

All specimens were printed on a DBZ AION 500 rapid prototyping machine shown in Figure 1. Custom printing profile is used to control the slicing/printing software which allows printing in a single specified raster orientation for the entire specimen. Each specimen was printed individually at the center of the printing bed

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in order to produce uniformity in the samples as much as possible. For the extrusion of the filaments the nozzle temperatures are maintained at which the filament material melts at a particular time. The PLA material has been extruded at 200°C and at a speed of 100 mm/sec with the heated bed surface at 80°C. The ABS material got extruded at 229°C at a speed of 100mm/sec having the heated bed surface temperature of 80°C. All specimens were printed with the same generic brand of PLA & ABS filaments from two 1-kg spools purchased together. Figure 2 shows the raster orientation tested and their identification at an angle of 45°C.

Fig 1. DBZ AION 500 rapid Prototyping

Figure 2: Raster orientation at an angle of 45°

A. TENSILE TEST:

For finding out the Ultimate Tensile strength of the specimens the samples were prepared as per the ASTM-D638 standard (Figure 3). The tests were conducted using Instron 8801 universal loading machine. The tests were conducted at room temperature. Figure 4 shows the testing setup for tensile testing of the specimen. Three specimens were taken for test for each type of polymer for considering the average as final value. The sample is held between the two load cells and the load is applied for 25kgf strain gauge load cell.

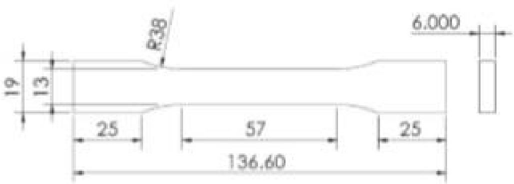

Fig 3. Tensile test specimen dimensions (in mm)

Fig 4. Tensile Test On Instron 8801 Universal Loading Machine

The Instron wedge was displaced at the rate of 3 mm/minute. The data is obtained from the computer and data acquisition system monitor continuously until the specimen reaches its UTS until it breaks.

B. COMPRESSIVE TEST

For finding out the compressive strength of the specimens the samples were prepared as per the ASTM-D695 standard as seen in figure 5. The tests were conducted using Instron 8801 universal loading machine. The tests were conducted at room temperature. Figure 6 shows the testing setup for tensile testing machine. Three specimens were taken for test for each

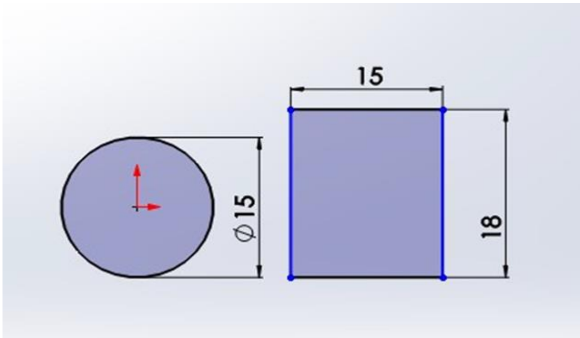

Fig 5. Bending Test Specimen Dimensions (In Mm)

type of polymer for considering the average as final value.

Fig 6 Compression test on Instron 8801 universal loading machine

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The sample is held between the two load cells and the load is applied for 25kgf strain gauge load cell. The Instron wedge was displaced at the rate of 3mm per minute. The computer and data acquisition system monitor continuously until the specimen reaches its Compressive limit.

C. FLEXURAL TEST

For finding out the 3-point flexural test of the specimens. The samples were prepared as per the ASTM-D790 [10,11] standard as seen in figure 7. The tests were conducted using Instron 8801 universal loading machine. The tests were conducted at room temperature. Figure 8 shows the testing setup for flexural testing of the 3d-printed specimen.

Fig 7. Bending Test Specimen Dimensions (In Mm)

Three specimens were taken for test for each type of polymer for considering the average of the three as final value. The sample is held between the two load cells and the load is applied for 25kgf strain gauge load cell. The Instron wedge was displaced at the rate of 3 mm per minute. The computer and data acquisition system monitor continuously until the specimen reaches its maximum flexural limit.

Fig 8. Flexural test set up

D. MICROHARDNESS TEST

The samples taken for this test were as shown in the figure 9.

Fig 9. Sample used for the Micro hardness testing

Micro hardness measurement was performed as per ASTM Standard at room temperature using Shimadzu HMV-G Series outfitted with a Vickers square pyramidal diamond indenter (136^{o}) as seen in figure 10. The tests were performed at the load of 50grams at a dwell time of 10 sec. the final deformation was measured after the load release using the micrometer eyepiece of the optical microscope. The test was performed in equidistant steps of 100-150µm along the necking region into the cold drawn area. The micro hardness value (MPa). The microhardness values were acquired directly from the digital display.

Fig 10. . Microhardness Tester (Shimadzu HMV-G Series)

E. SURFACE ROUGHNESS

Surface Roughness measurement was performed as per ASTM Standard at room temperature using Mitutoyo Portable Surface Roughness Measurement as shown in figure 11. The probe moves forward and backward on the surface of the specimens. The equipment calculates (Ra) and (Rz) an arithmetical mean roughness and mean roughness depth values.

Fig 11. Mitutoyo Portable Surface Roughness Measurement

F. MICROSTRUCTURES

Microstructure of three materials was taken from the Leica DM ILM Inverted Microscope. Microstructures were taken at room temperature as shown in figure 12 This Microscope acquires microstructure from 10µm - 100µm. High-performance optics give crisp, clear image resolution and contrast in incident light, brightfield, polarization contrast, and fluorescence. It is designed to handle large samples of objects by saving time while performing testing of large sample as seen in figure 12.

Fig 12. Optical Microscope

III. RESULTS AND DISCUSSIONS

The Ultimate tensile strength values are compared in the table 1

Table-1: Comparison of Ultimate tensile strength between the ABS, PLA and Layered ABS and PLA material

Specimen Label	Maximum load (KN)	Breaking load (kN)	Load at 2% strain (kN)	Ultimate Tensile Strength (MPa)
ABS	0.67	0.44	0.44	13.42
PLA	1.02	0.98	0.71	20.34
Sandwich of ABS and PLA	0.72	0.5	0.53	14.46

From the results obtained during the Tensile test it is observed that PLA has the higher value than the other two thermoplastics.The compression strength values are compared in the table 2

Table-2. Comparison of Compression strength between the ABS, PLA and Layered ABS and PLA material

Specimen label	Maximum Load (N)	Compressive Strength (MPa)	Compressive strain at Maximum Comp. load (mm/mm)
ABS	*3103.28*	*20.16*	*0.36544*
PLA	*5222.39*	*33.93*	*0.42582*
Sandwich of PLA and ABS	*3203.44*	*20.81*	*0.4278*

It is observed from the table 2 that the compressive strength of the PLA and Sandwich are same. The Flexural strength values are compared in the following table 3

Table 3: Comparison of Flexural strength between the ABS, PLA and Layered ABS and PLA material

Specimen label	Maximum load (N)	Maximum Stress (MPa)	Flexure strain at Maximum Flexure stress	Flexure extension at Maximum Flexure load (mm)
ABS	84.98737	47.22	0.0334	8.87735
PLA	32.17682	17.88	0.06392	4.63891
Sandwich of PLA and ABS	34.34876	19.08	0.06859	9.52694

From the above table 3 the Sandwich sample showed maximum flexural strength.The micro hardness values are compared in the following table 4

Table 4: Comparison of micro hardness between the ABS, PLA and Layered ABS and PLA material

Specimen Label	Vickers Hardness
ABS	129.6
PLA	125.33
Sandwich of ABS and PLA	125.6

The micro hardness values when compared showed almost similar values.

The Surface Roughness Values Are Compared In The Following Table 5

Specimen Label	R_A (µm)
ABS	9.40
PLA	6.73
Sandwich of ABS and PLA	9.59

The surface roughness of ABS and Sandwich are same where as PLA has less value. The microstructures shown in figures 11, 12, 13 showed homogenous distribution of the particles and are uniform in structure.

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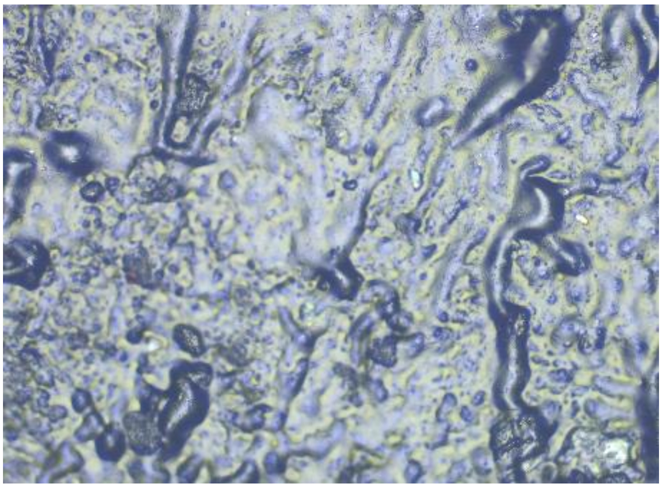

Fig 11. Microstructure of ABS

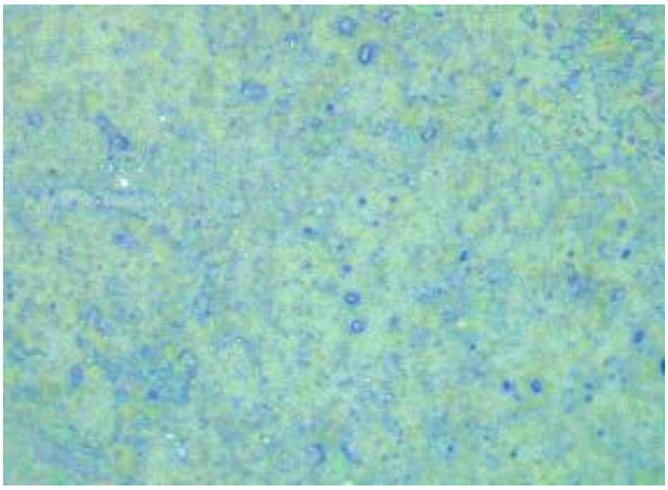

Fig 12. Microstructure of PLA

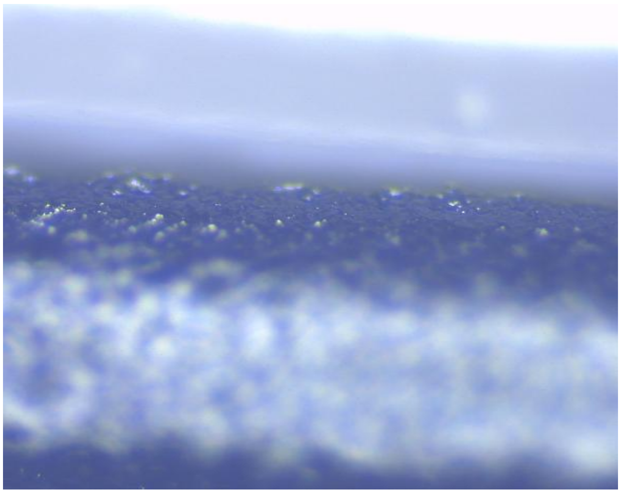

Fig 13. Microstructure of Sandwich structure

IV CONCLUSIONS

1. The Ultimate Tensile Strength (UTS) value of PLA is found out to be superior to ABS and multilayer specimens.
2. The compressive strength of PLA and Sandwich was equal. ABS has minimum value.
3. The maximum flexural stress was observed in Sandwich.
4. Micro hardness of all the three specimens was almost equal.
5. Surface Roughness of Sandwich and ABS were found to be similar but PLA exhibited minimum surface roughness.
6. The microstructures of all the three samples are of uniform structure.
7. From the results obtained Sandwich of ABS and PLA exhibited more flexural strength and higher elongation before breaking. This layered Thermoplastic can be used where there is flexural strength requirement. Under such applications the usage of ABS can be minimized and be replaced with the sandwich plastic inorder to reduce the environmental effects.

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