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Experimental analysis and comparison of mechanical properties of different materials used in Rapid prototyping

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Abstract

Rapid prototyping (RP) technique is widely used in engineering for producing complex conceptual and functional solid models which are used for 3D printing in Fused Deposition Modelling (FDM) technique. In this work, two commonly used materials Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) specimens as well as their combinations of different proportion like 75% PLA with 25% ABS and vice versa were manufactured using entry level 3D printer as the ABS having a problem of warping as it cools down therefore it can be effectively used with PLA and may produce better material of mechanical properties. Experiments such as tensile strength test, flexural strength test and deflection temperature test were performed to measure and compare the mechanical properties as per the ASTM standards. Results obtained are validated by comparing the test results with the previously available results. It is found that the performance of 75% PLA with 25% ABS combination has shown better test results compared to the other cases considered on account of mechanical properties.

***Keywords**:* Rapid Prototyping, PLA, ABS, Fused Deposition Modelling, Mechanical Properties

1. Introduction

Manufacturing technologies can be of various categories such as formative, subtractive or additive. Rapid prototyping is an additive manufacturing technology that has been developed in the mid of 1980, which enables the manufacturing of parts directly from a digital 3D CAD model without any use of physical tool and with different kinds of materials. Nowadays rapid prototyping has globally widespread and gained industrial acceptance as a means of quickly and economically producing large quantities of physical objects. At present, the designers are experiencing market pressure to develop a complex variety of different products in a short period of time, which empowers to the need to reduce manufacturing costs and to focus on the integration of product development process with rapid manufacturing technology. In addition to its commercial applications, rapid prototyping tool influence the ways people create complex objects with virtually no prerequisite skill.

Computer Numeric Control (CNC) machining or any other type of machining process is a subtractive method of manufacturing a product, as material is removed from a single block of material. After the machining process, the machined product requires post finishing and fabrication to manufacture the final product. But rapid prototyping is an additive manufacturing (AM) technique that manufacture parts by adding material ,instead of reducing it by turning, milling or other conventional machining techniques[3] .Also it has been defined as "process of joining materials to make parts from digital 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies."

Rapid prototyping is accomplished using computer software packages such as Computer Aided Design (CAD) file (solid modelling software like CATIA, Uni-Graphics, Solid Works, Pro-E and Auto CAD) tool. The mechanism is almost identical for all RP process i.e. addition of one layer over another in X-Y plane and the addition of material occurs in Z direction.

1.2 Rapid Prototyping Techniques

RP systems take information from a CAD solid model file via an STL file and convert it into a sliced model. They then use this information to drive an SFF process (defined below) to physically build the layers. These layers are deposited on top of each other to form the final part.

1. Solid Freeform Fabrication (SFF): SFF refers to a collection of techniques for manufacturing solid objects by the sequential delivery of energy and/or material to specified points in space to produce that solid.

2. 3D Printing (3DP): 3DP refers to the category of RP processes which implement the simplest of the SFF technologies to achieve fast and affordable 3D printers. Whilst 3DP is currently a term favoured by the media, its scope is limited to the simplest of SFF techniques.

RP systems have following limitations:-

a) It is sometimes difficult and occasionally impossible to remove support material from cavities.
b) Distortion, shrinkage and warping can occur due to residual stresses in print material solidification.
c) Feature damage can occur during support material removal.
d) Build features must not be too small, too closely spaced, or require accuracy beyond the technology's capabilities.
e) Overhanging features may affect the surface flatness.
f) Surface finish is dependent on material, build orientation, layer thickness, sloped surfaces, intricate features, and curves surfaces. [Surface finish is generally rougher than that from a part made using traditional subtractive techniques such as turning, milling and grinding].
g) The maximum size of the part is defined by the build volume of the RP system.

1.2.1 Various rapid prototyping machines are as follows:-

- Stereolithography
- Jetted Photopolymer
- Single Jet Inkjet
- Selective Laser Sintering
- Laminated Object Manufacturing
- Fused Deposition Modelling
- Solvent jet printing

1.2.2 Fused Deposition Modelling(FDM) :

In this work, we are using FDM technique with PLA and ABS as filament material. Filament is fed into an extrusion head and heated to a semi liquid state. The semi liquid material is extruded through

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the head and then deposited in ultrathin layers from the head, one layer at a time. Since the air surrounding the head is maintained at a temperature below the material's melting point the material quickly solidifies.

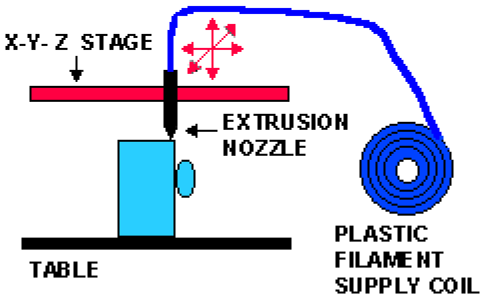


Figure1: Fused Deposition Modelling

2. Problem Identification

Effect of combining one material to that of different material layer by layer will be analysed through its mechanical properties. Tests performed are tensile strength test, flexural test and deflection temperature test as per ASTM standard tests. Mechanical properties such as tensile strength, Young's modulus, strain at Yield Point and deformation (microstrains) will be analysed. Materials used are PLA, ABS and its combinations.

3. Experimental procedure

The two most common materials used for 3D printing in Fused Deposition Modelling are PLA and ABS. The later having a problem of warp as it cools down therefore if it can be effectively used with PLA and may produce better results in terms of mechanical properties. Four cases are considered as follows

i) Specimen 1 is made up of 100% PLA
ii) Specimen 2 is made up of 100% ABS
iii) Specimen 3 is made up of 75% PLA & 25%ABS
iv) Specimen 4 is made up of 25% PLA & 75% ABS

Three different types of tests were performed:

a) Tensile strength
b) Flexural strength
c) Deflection temperature test

All the test specimens were printed with the help of a rapid prototyping machine (FDM) and glued with the help of acetone and ABS solution since ABS is soluble in acetone and after dissolving in acetone it produces an adhesive property which binds well with PLA and due to same material i.e. ABS it has a natural property of binding with each other as acetone is highly volatile in nature therefore the adhesive dries up very easily and the resultant is a layer by layer printed different material single specimen if ABS would have been directly printed above PLA or vice versa the adhesion strength between them would have been weak and therefore, the layers would part away in between since small thickness layers of ABS are easy to be printed therefore it will help to create a material having the desired properties of both ABS and PLA in the right percentage through the right proportion or number of layers all the layers printed are of right thickness and the total thickness is as per the ASTM standard

Properties of PLA are as follows

a. It is derived from renewable resources like corn starch or sugar cane.
b. Plastics that are derived from biomass are known as bio plastics (e.g. PLA).
c. PLA is biodegradable.
d. It can be produced from already existing manufacturing equipment this makes it relatively cost efficient to produce i.e. those designed and originally used for petrochemical industry plastics.
e. PLA has the second largest production volume of any bioplastic.
f. Most common applications are plastic films, bottles, and biodegradable medical devices (e.g. screws, pins, rods, and plates that are expected to biodegrade within 6-12 months).
g. PLA constricts under heat and is thereby suitable for use as a shrink wrap material.

Properties of ABS are as follows

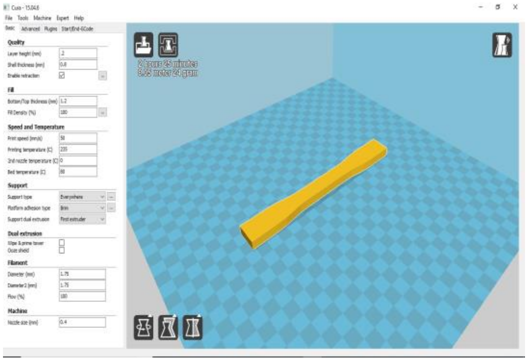
a. ABS is an opaque thermoplastic and amorphous polymer.
b. ABS has a strong resistance to corrosive chemicals and/or physical impacts.
c. It is very easy to machine and has a low melting temperature.
d. Most common applications are keys on a computer keyboard, power-tool housing, the plastic face-guard on wall sockets.
e. ABS is easily machined, sanded, glued and painted.
f. ABS is very structurally sturdy.
g. It doesn't have any known carcinogens, and there are no known adverse health effects related to exposure to ABS.

3.1 Modeling of Geometry

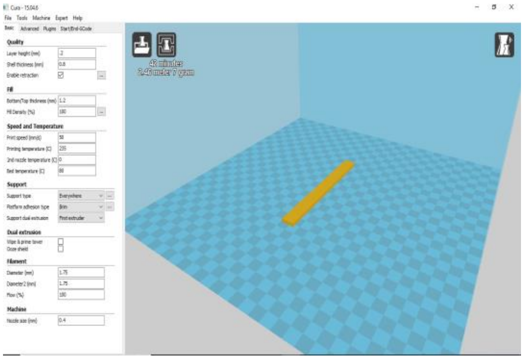
Graphic interfaces are often used to help in the creation and manipulation of the geometrical objects. There are numerous CAD software packages used for engineering design which can produce files containing the geometry of the designed engineering system. These files can usually be read by modelling software packages, which can significantly save time when creating the geometry of models. However, in many cases complex objects read directly from a CAD file may need modified and simplified before performing meshing or discretization.

After modelling of the specimens it is saved into Standard Tessellation Language (.stl) format. The saved file is then opened in a software. For this work Cura 15.04.6 is being used to convert the .stl file into G-codes which the rapid prototyping machine or FDM machine can understand. After creation of the codes the file is saved and shifted into a SD card and then the card is inserted into the machine, the machine then gives the option of choosing which file to be printed from the SD card. In this way all the specimens were printed.

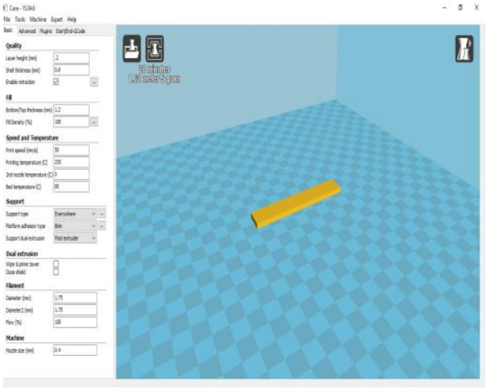
3.2 Cura 15.04.6 interface used for the creation of the codes for the three tests carried out:



(a)



(b)



(c)

Figure 2: (a) Dumbbell specimen for tensile test, (b) Specimen for flexural strength test, (c) Specimen for deflection temperature test

3.3 Tests carried out to check the mechanical strength of different specimens are as follows:

3.3.1 Tensile strength ASTM D638: The test is performed in UTM. This test method covers the determination of the tensile properties of unreinforced and reinforced plastics in the form of standard dumbbell-shaped test specimens when tested under defined conditions of pre-treatment, temperature, humidity, and testing machine speed. Tensile test specimens are given below:

(a)

(b)

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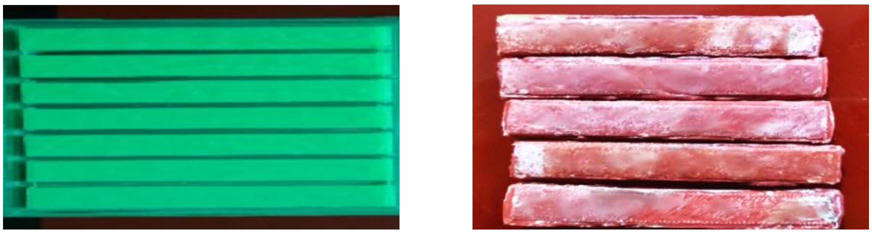
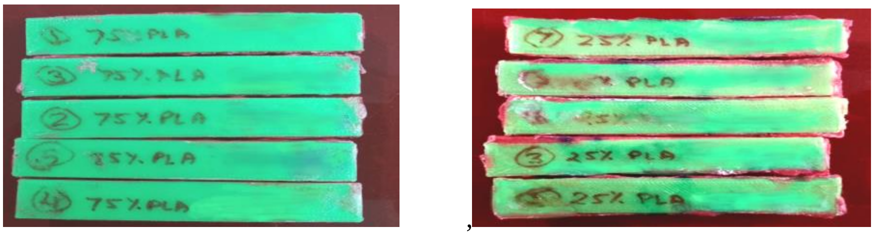
(c) (d)

Figure 3: (a) Specimen 1, (b) Specimen 2, (c) Specimen 3, (d) Specimen 4

3.3.2 Flexural Strength ASTM D790: In this test, a bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the supports. Flexural strength cannot be determined for those materials that do not break or that do not fail in the outer surface of the test specimen within the 5.0 % strain limit of these test methods.



(a) (b)



(c) (d)

Figure 4 : (a) Specimen 1, (b) Specimen 2, (c) Specimen 3, (d) Specimen 4

3.3.3 Deflection Temperature test ASTM D648: In this test a bar of rectangular cross section is tested in flat position as a simple beam with the load applied at its centre to give maximum fibre stresses of 0.455MPa or 1.82MPa. The specimen is immersed under load in a heat-transfer medium provided with a means of raising the temperature at 2 ± 0.2°C/min. The temperature of the medium is measured when the test bar has deflected 0.25 mm. This temperature is recorded as the deflection temperature under flexural load of the test specimen.

(a) (b)

(c) (d)

Figure 5 : (a) Specimen 1, (b) Specimen 2, (c) Specimen 3, (d) Specimen 4

3. Results and Discussion

PLA and ABS specimens have been validated by comparing the experimental results with the available results. After validation two different combinations of PLA and ABS are being tested and analysed. The results are obtained by performing tests on five specimens for each test.

3.1 Results obtained for Tensile tests(ASTM D638)

Table 1. Tensile strength of specimen

Specimen	Mean Modulus of Elasticity (GPa)	Tensile Strength (MPa)		Mean value of Tensile strength (MPa)	Percentage Elongation at break (%)
		Minimum	Maximum		
Specimen 1	3.60	62.38	65.26	63.85	2.41
Specimen 2	2.04	34.82	37.91	36.27	5.40
Specimen 3	3.13	55.75	59.75	57.36	2.87
Specimen 4	2.49	47.54	50.48	49.03	4.56

The tensile strength of PLA is 60 - 65 MPA therefore results obtained for specimen 1are validated [5]
The tensile strength of ABS is 30 - 37 MPA therefore results obtained for specimen 2 are validated [1]

Specimen-3 has shown better results compared to Specimen-4 therefore the former will be considered as the better as the cost to the mechanical properties is good.

3.2 Results obtained for Flexural tests (ASTM D638)

Table 2. Flexural strength of specimen

Specimen	Flexural Strength (MPa)		Mean value of Flexural Strength (MPa)	Mean Flexural Modulus (Gpa)
	Minimum	Maximum		
Specimen 1	90.44	88.46	92.83	2.98
Specimen 2	57.18	55.31	58.63	2.25
Specimen 3	96.92	95.54	98.25	2.61
Specimen 4	85.96	84.29	87.38	2.42

The flexural modulus of PLA is 3 GPA for specimen 1 therefore our work has been validated [8]
The flexural modulus of ABS is 2.5 GPA for specimen 2 therefore our work has been validated [8]

Specimen-3 had shown better results compared to Specimen-4 therefore the former case will be considered as the better.

3.3 Results obtained for Deflection temperature tests (ASTM D638)

Table 3. Deflection temperature of specimen

Specimen	Tensile Strength (MPa)		Mean value of Tensile strength (MPa)
	Minimum	Maximum	
Specimen 1	50.1	50.7	50.44
Specimen 2	58.8	58.4	58.64
Specimen 3	49.3	49.5	49.54
Specimen 4	43.1	43.9	43.60

Specimen-3 is nearly equivalent to Specimen-1 whereas Specimen-4 has shown considerable difference than Specimen- 2 therefore Specimen-3 had shown better temperature resistance than Specimen- 4.

4. Conclusion

After performing tests on different specimens many important conclusions are made up :

The specimen 3 showed better results for tensile and flexural strength as compared to the other cases considered. The deflection temperature of plastics under flexural load tests of specimen 3 is nearly equivalent to specimen 1 whereas specimen 4 has shown considerable difference than specimen 2 therefore specimen 3 can be considered as the best combination out of all the cases considered.

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