International Journal of Scientific Research in Computer Science, Engineering and Information Technology

ISSN : 2456-3307 OPEN ACCESS

Available Online at : www.ijsrcseit.com

doi : https://doi.org/10.32628/CSEIT182548

Advanced Testing and Analysis of Mechanical Properties for 3D Printing Materials

Ganesh Kumar Reddy Bommavaram[1], Teja Naga Vardhan Peddi[2]

[1]Indian Institute of Aeronautical Engineering (IIAE), Dehradun, India

[2]Jawaharlal Nehru Technological University, Kakinada, India

Article Info

Publication Issue :

Volume 7, Issue 4

July-August-2021

Page Number : 673-677

Article History

Accepted: 01 Aug 2021

Published: 12 Aug 2021

ABSTRACT

The recent developments in 3D printing technology enable digital manufacturing in mass-scale distribution. Also, the ready availability of 3D printers for the public at low costs and high mechanical properties makes the scientists look at the properties of the 3D printing materials. However, polymers are mainly used to make 3D objects, and they generally have low mechanical properties. So, there is an urgent need to characterize and analyze the mechanical properties to assess which 3D printing materials have better properties.

This work is aimed at finding the best 3D printing material from existing materials. In this work, initially, the mechanical properties of the 3D printing polymers like polylactic acid (PLA) and lay Wood have been analyzed. This work would propose the best 3D printing material from current basic 3D printing materials with improved mechanical properties.

Keywords : 3D printing materials, Mechanical properties, Polylactic acid (PLA), Material characterization, Digital manufacturing

INTRODUCTION

1.1 Importance of 3D Printing

As technology advances daily, constraints like time, dimensional accuracy, surface finish, etc., play a major role in industrial territory. The conventional machining process does not solve these problems. For ease in their lives, people are also looking into the production of small, often-used parts. As need and necessity lead to discovery, engineers have looked into a manufacturing process called Additive Manufacturing to ensure the needs of people and industries.

3D Printing is a process where physical objects are prepared by laying down many successive thin layers of material. It converts the digital data of the object into physical form by adding layer by layer of material. The basic principle behind 3D Printing is additive manufacturing, where objects are prepared by joining materials to make objects from 3D model data. Additive manufacturing technology is a combination of many manufacturing processes that makes any product possible to make and eliminates many constraints imposed by conventional manufacturing, which leads to more futuristic market opportunities. It is also known as Rapid Prototyping, where it is used to quickly fabricate a scale model of a physical part using three-dimensional CAD data.

1.2 Types of 3D printing

There are so many times of additive manufacturing processes, but mainly classified into three types based on the initial form of their material, they are:

- Solid-based Additive Manufacturing (AM):

The building material used in this type is in solid state. The solid form can include shapes like wire, rolls, laminates, and pellets (except powder). This method is mostly used compared to powder-based.

Examples:

1) Fused deposition modeling (FDM)
2) Selective deposition Lamination (SDL)
3) Laminated Object Manufacturing (LOM)
4) Ultrasonic Consolidation

- Liquid-based Additive Manufacturing (AM):

The building material used in this type is in the liquid state. This method is mostly used compared to solid-based.

Examples:

1) Stereolithography Apparatus (SLA)
2) Multi-jet Printing (MJP)
3) Polyjet 3-D Printing
4) Solid Object Ultraviolet-Laser Printer (SOUP)
5) Rapid Freeze Prototyping

- Powder based Additive Manufacturing (AM):

The building material used in this type is powdered. This method is mostly used compared to solid-based.

Examples:

1) Selective Laser Sintering (SLS)
2) Color Jet Printing (CJP)
3) Laser Engineered Net Shaping (LENS)
4) Electron Beam Melting (EBM) etc.

The important AM technologies among the above processes are

1) Stereolithography Apparatus (SLA)
2) Fused Deposition Modeling (FDM)
3) Selective Laser Sintering (SLS)

1.3 Terminology

The common terminology used in 3-D printing is Infill percentage, Orientation Angle, Bed Temperature, Layer thickness, Nozzle temperature, etc.

To make use of these 3-D printing methods, we need materials to print. There is a point where 3-D printing materials play a major role. The objects manufactured from these materials are used as prototypes and also may be in working machines. To make sure that they are safe to use, we need to know their properties. Hence, the project concentrates on finding and comparing the mechanical properties and characteristics of the materials.

LITERATURE REVIEW

Tymrak B.M et al(2014) studied the basic tensile strength and elastic modulus of printed components using realistic environmental conditions for standard users of a selection of open-source 3-D printers. The results find average tensile strengths of 28.5 MPa for ABS and 56.6 MPa for PLA with average elastic moduli of 1807 M Pa for ABS and 3368 MPa for PLA. It is clear from these results that parts printed from tuned, low-cost. Rep Rap printed parts to be used in engineering applications the mechanical properties of printed parts are well known.

Joshua M. Pearce et al. (2003) studied Rep Rap printed parts printed in realistic environmental conditions that can match and even perform commercial 3-D printers using proprietary FDM in terms of tensile strength with the same polymers. The tensile strengths of the large sample set of Rep Rap prints fluctuated. This study determines the effect of color and processing temperature on the material properties of Lulzbot TAZ-deposited PLA in various colors. Five colors (white, black, blue, grey, and natural) of commercially available filament processed from 4043D PLA are tested for crystallinity with XRD and tensile strength following ASTM D638, and the micro-structure is done with an environmental scanning electron microscope.

Lu Wang et al. (2014) studied an investigation of two printing parameters, layer height (0.2 and 0.4 mm) and plate temperature (30 and 160 °C), on the Izod impact strength of printed PLA.X-ray diffraction (XRD) analysis confirmed the existence of α crystals in parts printed from 160 °C-plate temperature and α' crystals in those printed at 30 °C plate temperature. Parts printed with a 160 °C (plate temperature) had higher crystallinity. Polarized optical microscope (POM) observations illustrated that the plate temperature of 160 °C and layer height of 0.2 mm induced higher crystallinity, smaller crystals, and inter-facial crystal bands. The Izod impact strength of printed PLA at higher plate temperatures was up to 114% higher than injection molded PLA made using conventional molding parameters.

Ossi Martikka1 et al. (2018) studied the tensile properties and impact strength of two 3D-printed commercial wood-plastic composite materials and compared them to those made of pure polylactic acid. Relative to weight – mechanical properties and the effect of the amount of fill on the properties. These results indicate that parts made of wood-plastic composites have notably lower tensile strength and impact strength than those made of pure polylactic acid and mechanical properties can be considered sufficient for low-stress applications, such as visualization of prototypes and models or decorative items.

Cezary Grabowikl et al (2002) studied tensile tests carried out for specimens made of the selected group of filament materials. The selected group of filament materials involved the group of wood, PLA. Herein, it should be noticed, that technical data sheets that are delivered by filament materials producers include data that are valid for only one specific printing direction. This printing direction is deliberately selected, in such a way that ensures the best material characteristics. This research results allow us to make comparison between a catalogue data and data obtained in the printing process.

Casavola Caterina et al. (2015) studied the mechanical behavior of FDM parts by the classical laminate theory (CLT). To reach this objective, the values of the elastic modulus in the longitudinal and transverse directions to the fiber (E1, E2), the Poisson's modulus (v12), and the shear modulus (G12) will be experimentally measured. In this process, the model is built as a layer-by-layer deposition of a feedstock wire. The Fused Deposition Modelling (FDM) evolved from a rapid prototyping technique towards a rapid manufacturing method, changing the main purpose of producing finished components ready for use.

John Ryan C. Dizona et al. (2017) provided a brief discussion about AM and also the most employed AM technologies for polymers. The commonly used ASTM and ISO mechanical test standards have been taken into consideration to test the strength of the 3D-printed parts. Also, a summary of an exhaustive amount of literature regarding the mechanical properties of 3D-printed parts is included, specifically, properties under different loading types such as tensile, bending, compressive, fatigue, impact, and others. Properties at low temperatures have been discussed. The effects of fillers as well as post-processing on the mechanical properties have been discussed

Russell A. Giordano et al(1997)studied reports on the mechanical properties of 3D-printed PLLA parts. 3D printing is a solid free-form fabrication process that produces components by ink-jet printing a binder into sequential powder layers. Test bars were fabricated from low and high-molecular-weight PLA powders with chloroform used as a binder. The binder printed per unit line length of the powder was varied to analyze the effects of printing conditions on the mechanical and physical properties of the PLA bars. Furthermore, cold isostatic pressing was performed after printing to improve the mechanical properties of the printed bars.

Dietmar W. Hutmacher et al. (2001) studied the FDM method, introducing a new technique for the design and fabrication of tailor-made scaffold architectures for tissue engineering applications. The honeycomb design resulted in good mechanical properties. PCL scaffolds showed excellent biocompatibility with human fibroblast and period steal cell culture systems.

Research Gap

- Work is needed to address the impact of post-processing on the mechanical properties of the finished products.
- Future work is needed to test these factors to assist a broader application of distributed manufacturing with Rep Rap.

- It can be researched how the mechanical properties of FDM-made WPC items can be improved to more environmentally sustainable manufacture both in the industry and at home.
- Specimens built vertically are not included in this work by the FDM technique.
- The process parameters (extrusion temperature, feed rate, etc.) that influence the mechanical behavior of the finished part are not taken into account and they will be included in future developments.

MATERIALS & METHODOLOGY

3.1 Fused Deposition Modeling

It is also called filament-free form fabrication. It is a 3D printing process that uses a continuous filament of a thermoplastic material. Filament is fed from a large coil through a moving, heated printer extruder head, and is deposited on the growing work. The print head is moved under computer control to define the printed shape. Usually, the head moves in two dimensions to deposit one horizontal plane, or layer, at a time; the work or the print head is then moved vertically by a small amount to begin a new layer. The speed of the extruder head may also be controlled to stop and start deposition and form an interrupted plane without stringing or dribbling between sections.

Fused filament printing is now the most popular process in 3d printing. Other techniques such as photopolymerization and powder sintering may offer better results, but they are much more costly. The 3d printer head or 3d printer extruder is part of material extrusion additive manufacturing and is responsible for raw material and forming it into a continuous profile. A wide variety of filament materials are extruded, including thermoplastics such as acrylonitrile butadiene styrene (ABS), poly lactic acid (PLA), high-impact polystyrene (HIPS), thermoplastic polyurethane (TPU) and aliphatic polyamides (nylon).

3.1.1 Process

3D printing, also referred to as Additive manufacturing (AM), involves manufacturing a part by depositing material layer by layer. There is a wide array of different AM technologies that can do this, including material extrusion, binder jetting, material jetting, and directed energy deposition. These processes have varied types of extruders and extrude different materials to achieve the final product.

3.1.2 Material Extrusion

Fused filament fabrication (FFF) uses material extrusion to print items, pushing feedstock material through an extruder. The hot end consists of a heating chamber and a nozzle. The heating chamber hosts the liquefier, which melts the feedstock to transform it into a thin liquid. It allows the molten material to exit from the small nozzle to form a thin, tacky bead of plastic that will adhere to the material it is laid on. The nozzle will usually have a diameter of between 0.3 mm and 1.0 mm. Different types of nozzles and heating methods are used depending on the material to be printed. FFF begins with a software process, which processes an STL file (Stereo Lithography file format), mathematically slicing and orienting the model for the build process. If required, support structures may be generated. The nozzle can be moved in both horizontal and vertical directions and is mounted to a mechanical stage, which can be moved in the x and y planes.

Process: 1 – 3D Printer Extruder, 2 – deposited material (modeled part), 3 – controlled movable table

As the nozzle is moved over the table in a prescribed geometry, it deposits a thin bead of extruded plastic, called a "road" which solidifies quickly upon contact with substrate and/or roads deposited earlier.[20] Solid layers are generated by following a rasterizing motion where the roads are deposited side by side within an enveloping domain boundary. Stepper motors or servomotors are typically employed to move the extrusion head. The mechanism used is often an X-Y-Z rectilinear design, although other mechanical designs such as delta Bot have been employed. Once a layer is completed, the platform is lowered in the z direction to start the next layer. This process continues until the fabrication of the object is completed. For successful bonding of the roads in the process, control of the thermal environment is necessary. Therefore, the system is kept inside a chamber, maintained at a temperature just below the melting point of the material being deposited.

During FFF, the hot molten polymer is exposed to air. Operating the FFF process within an inert gas atmosphere such as nitrogen or argon can significantly increase the layer adhesion and lead to improved mechanical properties of the 3D printed objects. An inert gas is routinely used to prevent oxidation during selective laser sintering. During extrusion, the thermoplastic filament is introduced by mechanical pressure from rollers, into the liquefier, where it melts and extrudes. Flow geometry of the extruder, heating method, and the melt flow behavior of a non-Newtonian fluid are of main consideration in this part. The rollers are the only drive mechanism in the material delivery system; therefore, the filament is under tensile stress upstream to the roller and under compression at the downstream side acting as a plunger. Therefore, Compressive stress is the driving force behind the extrusion process. The force required to extrude the melt must be sufficient to overcome the pressure drop across the system, which strictly depends on the viscous properties of the melted material and the flow geometry of the liquefier and nozzle. The melted material is subjected to shear deformation during the flow. Shear thinning behavior is observed in most of the materials used in this type of 3-D printing. This is modeled using power law for generalized Newtonian fluids.

The temperature is regulated by heat input from electrical coil heaters. The system continuously adjusts the power supplied to the coils according to the temperature difference between the desired value and the value detected by the thermocouple, forming a negative feedback loop. This is similar to the heat flow rate in cylindrical pipe

3.1.3 Materials used

Plastic is the most common material for 3d printing via FFF and other EAM variants. Various polymers may be used, including acrylonitrile butadiene styrene (ABS), polycarbonate (PC), poly lactic acid (PLA), high-density polyethylene (HDPE), PC/ABS, polyethylene terephthalate (PETG), polyphenyl sulfone (PPSU) and high impact polystyrene (HIPS). In general, the polymer is in the form of a filament fabricated from virgin resins.

3.1.4 Applications

- Conceptual models
- Engineering models
- Functional testing
- Prototypes
- Fit, form, and functional Teat

- Pattern for investment.
- The MABS methods (material methyl acrylate ABI) material is particularly suitable for medical applications.

3.1.5 Advantages

- Complex parts can be produced with good accuracy and with low cost when compared to conventional
- Manufacturing process.
- No need for special tooling.
- As simple as printing of copy from a normal inkjet printer.
- Quick and cheap generation of models.
- There is no worry of exposure to toxic chemicals, lasers, or a liquid chemical bath.
- Complex geometric characteristics.
- It is a multi-material multi-functionally
- It is a Material flexibility and high resolution.
- Easy removal of support powder.
- Helps in quick testing of the product.
- Reduction in material cost, waste disposal cost, inventory cost, and material transportation cost.
- A wide range of materials is possible by loading the polymer.
- Low labor cost.
- Quick design modification.

3.1.6 Disadvantages

- FDM is a costlier process.
- The size of the output product is limited to a very small size. Raw material limitations. (No metal-based filaments can be used due to the requirement of high temperatures).
- FDM is a developing process.
- Rough surface topology.
- Nozzle clogging.
- Limitation in usable material.
- It is a time-consuming process.
- Low mechanical strength.
- Relative low accuracy.
- Poor strength in the vertical direction.
- Slow for building a mass part.
- High machinery cost.
- Unsuitability for very large products.
- The materials suite is currently limited to thermoplastics.

3.1.7 Properties

- Maximum build size : 20 x 20 x 20.

- Resolution in x, y : +/- (0.002 – 0.005).
- Resolution in Z : +/- (0.002-0.005).
- Speed : slow.
- Cost : Medium.
- Available materials : Thermoplastics (ABS, PC, ULTEM).
- ABS temperature used in FDM : 230 C.
- PLA temperature used in FDM : 180 C.

3.2 PLA:

PLA stands for polylactic acid. (**PLA**) is a biodegradable and bioactive thermoplastic aliphatic polyester derived from renewable biomass. It is produced via fermentation processes. PLA has been mainly used in biomedical applications and High-molecular, 100% renewable resources. In general, three methods can be used to produce high molecular mass PLA of about 100 000 Dalton: (a) direct condensation polymerization; (b) azeotropic dehydrative condensation, and (c) polymerization through lactide formation, the ring-opening polymerization. Currently, direct condensation and ring-opening polymerization are the most used production techniques. Ring-opening polymerization of the lactide needs a catalyst but results in PLA with controlled molecular weight Depending on the monomer used and controlling reaction conditions, it is possible to control the ratio and sequence of D- and L-lactic acid units in the final polymer. In this study, ring-opening polymerization was selected. The lactide was synthesized and PLA was produced.

The polymerization process of lactic acid is initiated by dehydration of the monomer, which generates pre-polymer chains consisting of oligomers and low molecular weight PLA. This process, starting from lactic acid involves three distinct stages: polycondensation, obtaining lactide, and ring-opening polymerization. Lactic acid (LA reagent grade) with 85 wt. % of purity was used in the polymerization process, and stannous octoate was used as a catalyst. In the first step, lactic acid was dehydrated to produce oligomers at temperatures of PLA 160 °C for 2 hours using the reaction system. The removal of product water from the condensation reaction was carried out at atmospheric pressure and employing the use of an inert atmosphere of N2. In the second step, the system was heated to a temperature of 220 °C and a reduced pressure of 200 mm Hg, so that the lactide produced (second step) could be recovered by distillation and collected in a condensate flask. The condenser was maintained at approximately 90 °C to prevent solidification of the product, for 4 hours of reaction. The lactide was then obtained by distillation, and the solid phase was recovered in the condensing flask. The crude product was washed with cold water, separated by filtration, and then dried overnight at a temperature of 40 °C. In the third and final step of the reaction, the lactide produced was mixed with the catalyst (1wt %) at a temperature of 140 °C for 2 hours and the PLA was produced. The functional groups of PLA and LA were analyzed by Fourier Transform Infrared Spectroscopy.

As PLA is a compound that has the highest possibility to replace synthetic non-biodegradable polymers without biodegradability, there have been many studies of the synthesis to improve its material properties or optical properties.

PLA can be made through a polymerization process from the lactic acid by polycondensation or ring-opening polymerization or can be made by direct methods such as azeotropic dehydration or enzymatic polymerization. Direct polymerization and ring-opening polymerization are the most generally used methods. PLA polymers range from amorphous glassy polymer to semi-crystalline and crystalline polymer with a glass transition. Currently, the SPI resin identification code 7 is applicable for PLA.

3.2.1 Properties

- Density : 1.210-1.430 g.cm^-3
- Melting point : 150 to 160 C
- Glass Transition temperature : 50-60C
- Crystallization : 5-40%.
- Tensile Strength : 4-6 kg/mm^2.
- Elongation : 3-4% brittle.
- Flexural strength : 9-11 kg/mm^2
- Impact strength : 50 kg cm/cm^2.
- Viscosity : 0.265-0.46+ M pa-s
- Shear modules : 2.4 GPA.
- Conductivity : 0.13 W/Mk.
- Diffusivity : 0.056 m^2/sec.

3.2.2 Advantages

- PLA is economical and transparent.
- It is very easy to control.
- This method is efficient and non-toxic.
- It has a high stability.
- Good thermoplastic material.
- Wide temperature range.
- Higher melt viscosity.
- It is a UV resistance.

3.2.3 Disadvantages

- PLA includes low resistance conditions of high heat and humidity.
- Low heat distortion temperature (HDT).
- Low flexibility.
- Time taking.
- Larger diameter fiber.
- At some point, it will biodegrade, this process will take several hundred years in a typical landfill.

3.2.4 Application

- PLA is used as a feedstock material in desktop fused filament fabrication 3D printers.
- Robotics, Medical use, Fashion, Dental.
- It has extensive applications in biomedical fields, including sutures, bone fixation material, drug delivery microspheres, and tissue engineering.

- PLA has been utilized as ecological material as well as surgical implant material and drug delivery systems and as porous scaffolds for the growth of neo-tissue.
- The fibers may be fabricated into various forms and may be used for implants and other surgical applications such as sutures. Tissue engineering is the most recent domain where poly (lactic acid) is being used and is found to be one of the most favorable matrix materials.
- The use of poly-lactic acid in these applications is not based solely on its biodegradability nor because it is made from renewable resources.

3.3 Lay Wood

The new filament Lay Wood is a mix of recycled wood fibers and polymer binders that can be melted and extruded just like any other 3D printer filament. Parts printed with Lay Wood have about the same properties as parts printed with PLA filament. The Lay wood filament is brittle and breaks quite easily, so you need to pay special attention when feeding it. It is common with fibrous and less viscous materials. The manufacturer-recommended printing temperature range is set between 175°C and 250°C. Once you are printing with the filament, you will notice that Lay wood has very good inter-layer adhesion. Depending on the resolution you will print, you will not see any layers, but the print will look like a solid piece of wood.

When we tested this material, we also found that it is important to make a small test print, to check if your extrusion rate is correct for this material. As an interesting side effect, playing with the temperature settings on the extruder allows you to obtain different finishes on the wood texture of your print. A higher temperature will create a darker color and the parts extruded at lower temperatures will obtain a lighter finish. The temperature setting that worked best for us was around 185-190°C. Towards the higher end of the recommended print temperatures (240-245°C), we found that the items printed became not only much darker but also a lot rougher. Therefore, if you are looking for "smoother" prints, we recommend staying in the 190-220°C range.

Another recommendation is to not keep this filament at high temperatures in the heat chamber without any extrusion going on (i.e. heating up the hot end for a print, but pausing/waiting before printing), as this will clog your nozzle with solid carbon. The same happens if you do not respect the maximum temperature extrusion indications and test printing with an even higher temperature than 250°C. Once burnt (i.e. carbonized), the filament will be a real pain to remove. It is quite easy and fun to print with it. It produces very unique prints with an interesting texture.

3.3.1 Properties

- Material : Brittle
- Temperature : 175 to 250C
- Extruder temperature : 175 to 250C
- Temperature recommendation : 185 to 190 C.

3.3.2 Advantages

- It is a good inter-layer adhesion.
- It will not see any layers but the print will look like a solid piece of wood.
- We can produce different finishes on the wood texture.

- It is a unique print with an interesting texture.

3.3.3 Disadvantages

- It breaks quite easily.
- It has less viscous material.
- It is a brittle material.
- It has a high temperature and will create a dark color.

3.4 Creality 10-S 3-D Printer

Figure 1. Creality 10-S 3-D printer

Table 1. Specifications of 3D printer

Build volume	300*300*400 mm
LCD screen	Yes
Nozzle diameter	0.4(can be replaced to 0.3/0.2mm)
Nozzle temperature	Below 250°C in normal state, max. 270°C
Support filaments	ABS / PLA/ TPU and so on
Material diameter	1.75mm
Print speed	150 mm/s
File format	G-Code, JPG, OBJ, STL
Host computer software	Cura

Other features	SD card off-line printing function

3.5 X-ray

Diffraction Test (XRD):

X-ray diffraction, abbreviated as XRD analysis is a non-destructive test method used to analyze the structure of materials. XRD is performed by directing an X-ray beam at a sample and measuring the scattered intensity as a function of the outgoing direction.

3.6 Hardness

It is the measure of the resistance to localized plastic deformation induced by either mechanical indentation or abrasion.

Formula:

$$\text{Average Hardness} = \frac{\text{Sum of the RHN values}}{\text{Total number of readings}} \qquad \text{Eq. 1}$$

Procedure:

1. The given specimen with a smooth surface is placed on the platform centrally.
2. The anvil is raised till the indicator above it comes into content with the specimen.
3. The anvil is further rotated till the small pointer on the inside dial comes to a set position which indicates the minor load is applied.
4. Then the large pointer is also brought to set, i.e., C-0 or B-30 position by rotating the dial.
5. The required load is added to the level depending upon the Indenter lied and the scale line. The load is applied by changing the handle to the load position.

3.7 Tensile Strength

Tensile strength is the capacity of the material to withstand loads tending to elongate. The resistance of a material to breaking under tension.

Formula:

$$\text{Breaking Stress} = \frac{\text{load at fracture}}{\text{original area of cross-section}} \quad \text{Eq. 2}$$

$$\text{Percentage of elongation} = \frac{\text{fluid length} - \text{initial length}}{\text{initial length} * 100} \quad \text{Eq. 3}$$

Procedure:

1. Measure the gauge length and diameter of the section using a micrometer and calipers.
2. Grip the specimen in between the upper and middle jaws.
3. Start the universal testing machine.
4. Begin the load application and record the load elongation data.
5. Take the readings more frequently.
6. Continue the load application till the failure occurs.
7. Stop the machine and remove the specimen.
8. By joining the two broken pieces of the specimen together, measure the final length.
9. Measure the diameter of the neck.

3.8 Compressive Strength

Compressive strength which withstands loads, tends to reduce size. The resistance of a material to breaking under compression.

Formula:

$$\text{Ultimate compressive strength of wooden specimen} = \frac{\text{load applied}}{\text{area of cross-section}} \quad \text{Eq. 4}$$

Procedure:

1. Measure the cross-sectional dimension of the specimen.
2. Place the wooden specimen on the table of the universal testing machine.
3. Switch on the universal testing machine.
4. Set the load indicator to zero.
5. Apply the load gradually and note the load at the failure.
6. Stop the machine and remove the specimen.
7. Repeat the above procedure for another specimen.

RESULTS

The specimens made from both the materials PLA and Lay wood are tested for tensile strength and Compressive strength using a Universal testing machine. The tensile strength of the PLA is given in the table below.

Table 2. Tensile strength of PLA

Name of material	Peak load KN	Tensile strength N/mm^2	C.H. Travel at peak (mm)	C.H. break at peak (mm)	Elongation %	Reduction area %
PLA	6.7	42.9	6.6	8.5	8.5	2.36

Figure 2. Tensile specimen of PLA after the test

The tensile strength results for lay wood are given in the table below

Table 3. Table showing Tensile strength of Lay Wood

Name of material	Peak load KN	Tensile strength N/mm²	C.H. Travel at peak (mm)	C.H. break at peak (mm)	Elongation %	Reduction area %
Lay wood	3.9	29.7	3.4	1.7	1.7	0.89

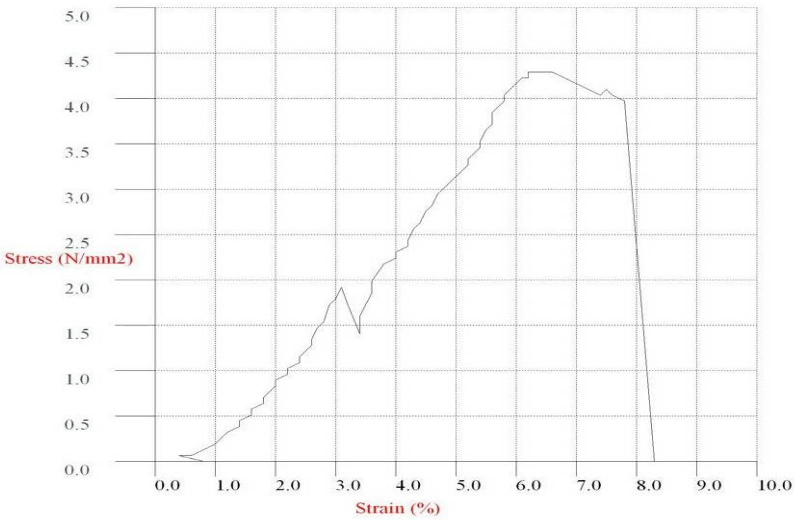


Figure 3. Stress-Strain graph of PLA

And like the tensile strength, the compressive strength is also found using a Universal testing machine (UTM) The compressive strength of PLA is given in the below table

Table 4. Compressive strength and Impact strength of PLA

Name of the material	Compressive strength N/mm^2	Impact strength N/mm^2
PLA	26	1.8

Lay wood compressive strength is given below in the table

Table 5. Compressive strength and Impact strength of Lay Wood

Name of the material	Compressive strength N/mm^2	Impact strength N/mm^2
LAYWOOD	25.5	0

Figure 4. Compressive Strength Testing of PLA using UTM

Now using the Rockwell hardness testing machine, we found out the hardness of the two materials. The diamond indenter of 1/4 inches and B scale is used.

The harness values of PLA are given in the table below

Table 6. Hardness values of PLA

S.no	Material	Indenter	Scale	Rockwell Hardness value (RHN)
1.	PLA	Diamond (1/4)	B	95
2.	PLA	Diamond (1/4)	B	94
3.	PLA	Diamond (1/4)	B	95
4.	PLA	Diamond (1/4)	B	96

5.	PLA	Diamond (1/4)	B	95
			AVG	95

The hardness values of Lay wood are given in the table below

Table 7. Hardness of Lay Wood

S.no	Material	Indenter	Scale	Rockwell Hardness value (RHN)
1.	Lay wood	Diamond (1/4)	B	79
2.	Lay wood	Diamond (1/4)	B	80
3.	Lay wood	Diamond (1/4)	B	80
4.	Lay wood	Diamond (1/4)	B	78
5.	Lay wood	Diamond (1/4)	B	82
			AVG	80

The nodularity and porosity of the materials are determined by using an Electron microscope and MICROCAM 4.0 software.

The result of nodularity for Lay wood is given below

Name :	NODULARITY	Application :	B1
Evaluation Date :	21/04/19	Opeator :	NONE
SampleInfo ID :	LAY WOOD	Microscope Obj :	Microscope Obj

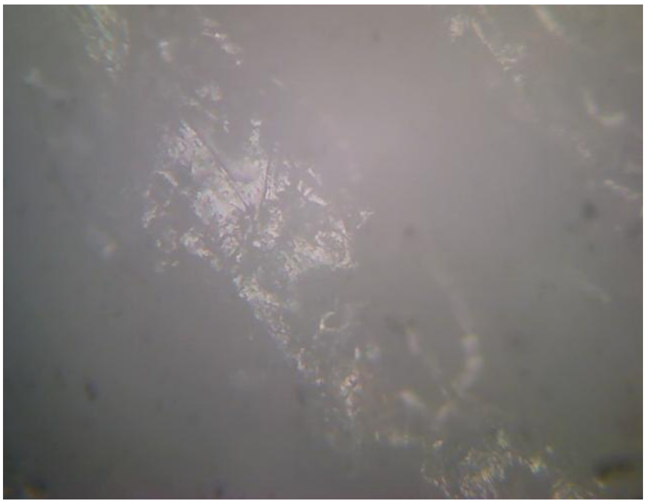


Figure 5. Microstructure of Lay Wood material

Table 8. Percentage of Nodularity in Lay Wood

Unit : Micron

Field	Total	Nodule	Nodule %	per mm.sqr	Max Area	Min Area	Max Peri.	Min Peri.
Field 1	76	60	78.95	28.2031	1283795.014	6.925	11680.586	10.526

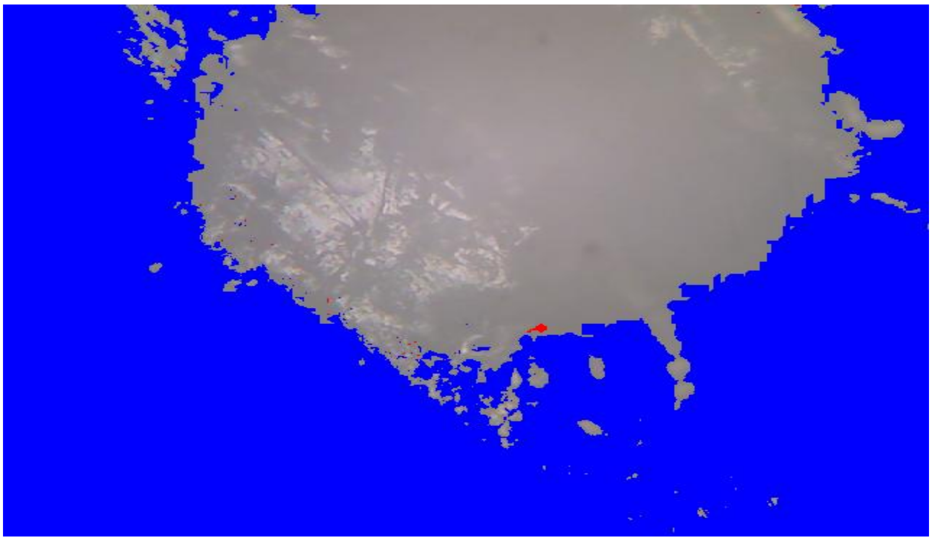
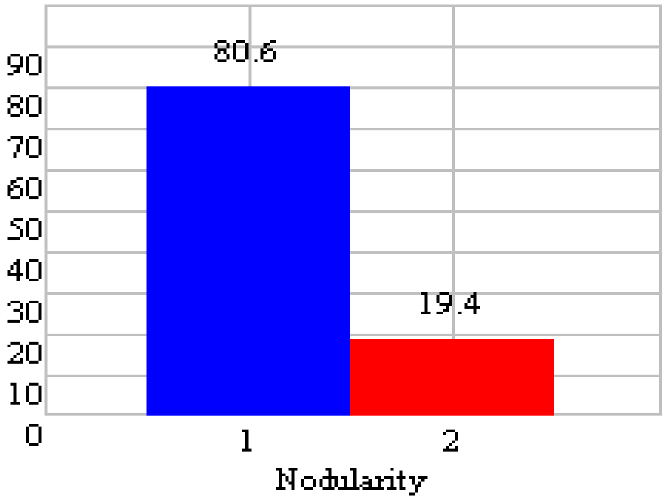


Figure 6. Graphs showing the variation between Nodularity and Non- Nodularity



The porosity of Lay wood is tested and given below.

Name :	POROSITY	Application :	B1
Evaluation Date :	21/04/19	Opeator :	NONE
SampleInfo ID :	Lay Wood	Microscope Obj :	Microscope Obj

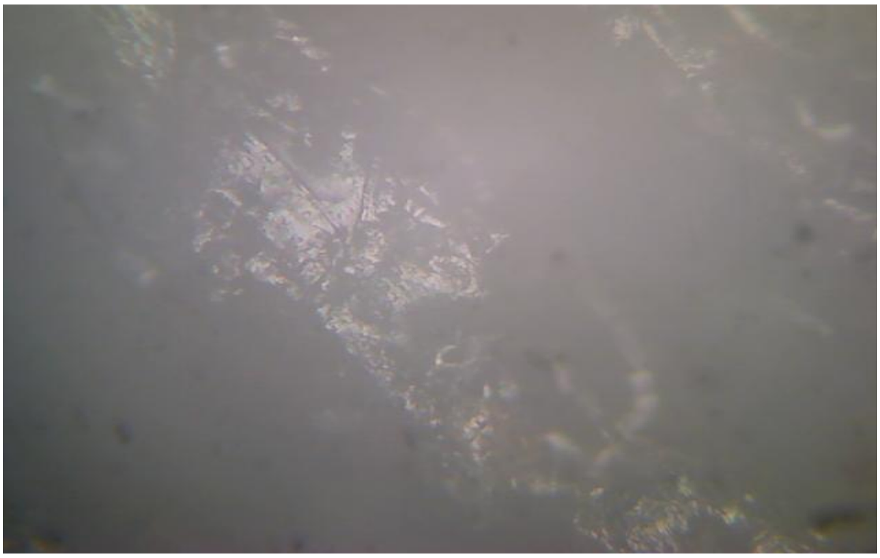


Figure 7. Micro-structure of Lay Wood

Table 9. Porosity percentage of Lay Wood

Unit : Micron

Field	Total	Pores %	Max. Peri	Min. Peri	Max. Area	Min. Area
Field 1	76	60.53	11680.5857	10.5263	1283795.0139	6.9252

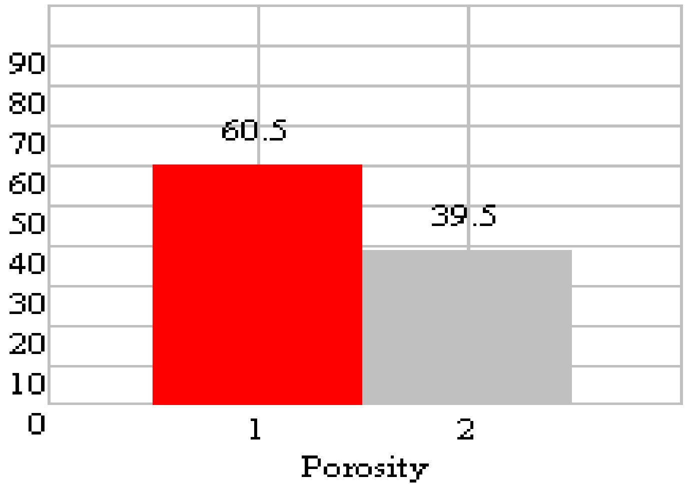


Figure 8. The graph between Porosity and Non-Porosity of Lay Wood

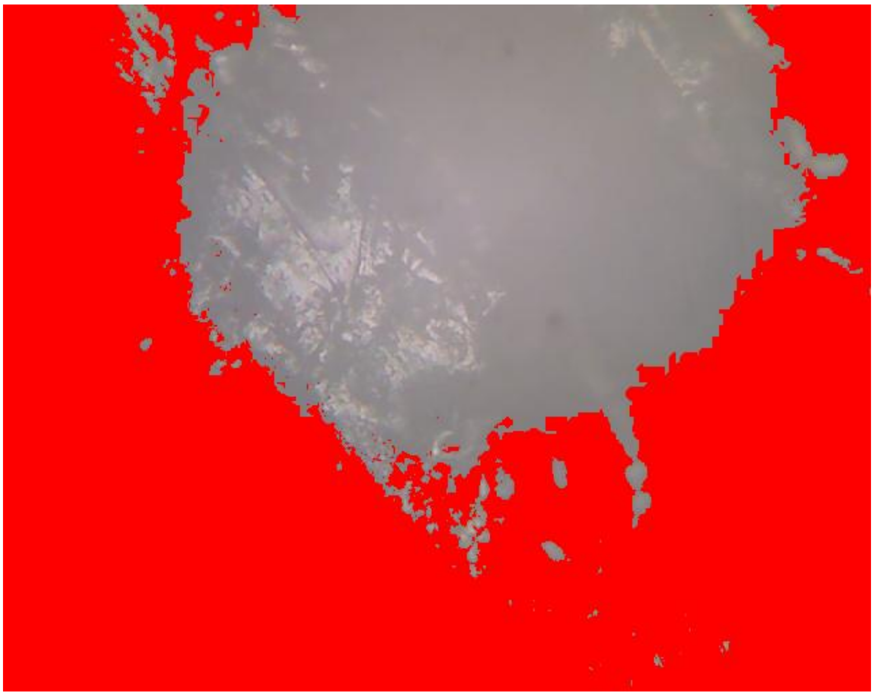
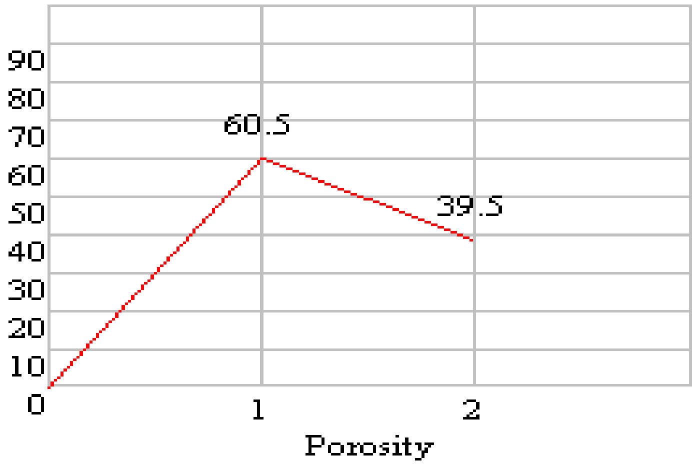


Figure 9. Micro-structure of Lay Wood after finding Porosity



The result of nodularity for PLA is given below

Name :	NODULARITY	Application :	B1
Evaluation Date :	21/04/19	Opeator :	NONE
SampleInfo ID :	POLY LACTIC ACID	Microscope Obj :	Microscope Obj

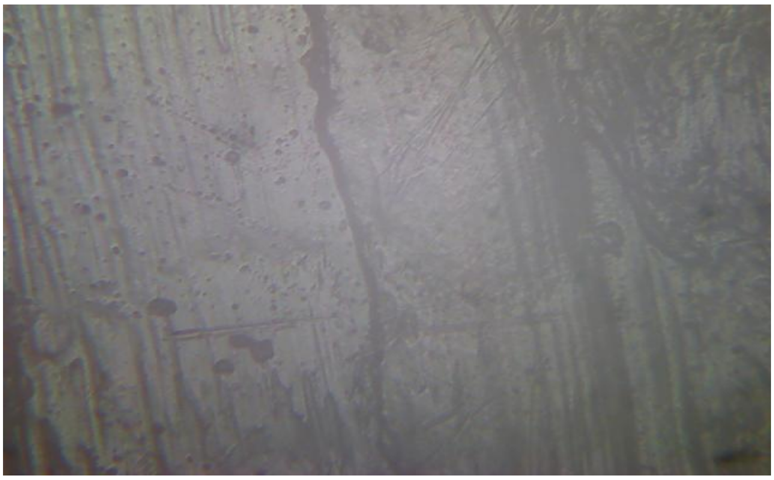
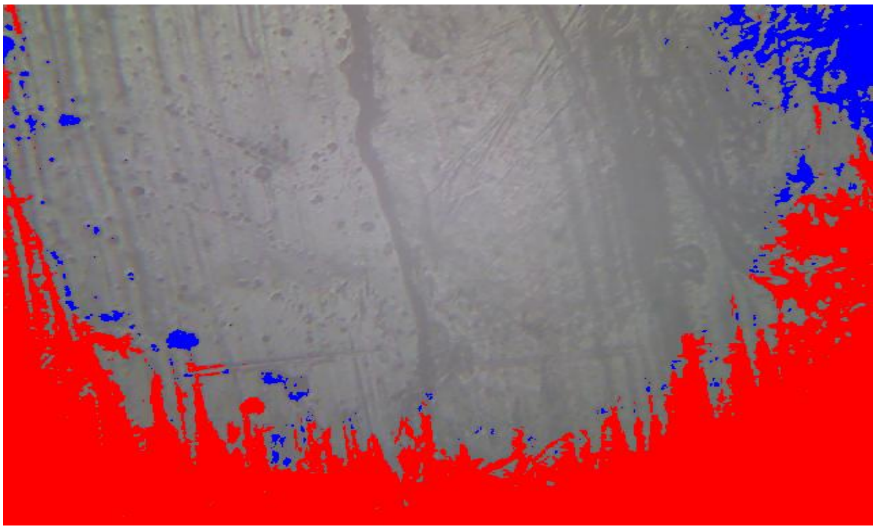


Figure 10. Micro-structure of PLA material

Table 10. Percentage of Nodularity in PLA

Unit : Micron

Field	Total	Nodule	Nodule %	per mm.sqr	Max Area	Min Area	Max Peri.	Min Peri.
Field 1	222	179	80.63	84.1393	40588.643	6.925	2550.179	10.526



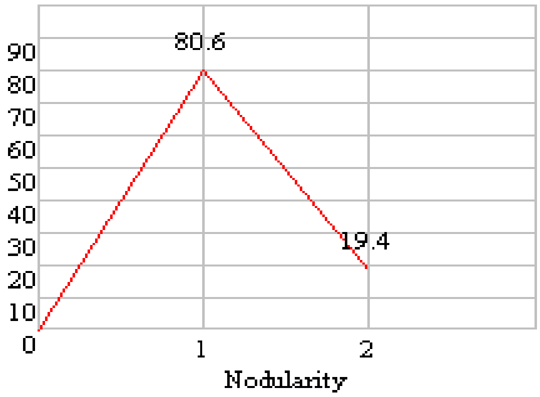
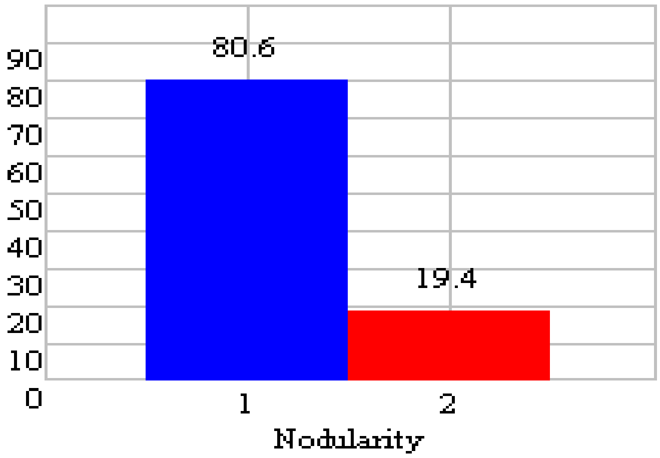


Figure 11. Graphs showing the variation between Nodularity and Non- Nodularity



The porosity of PLA is tested and given below.

Name :	POROSITY	Application :	B1
Evaluation Date :	21/04/19	Opeator :	NONE
SampleInfo ID :	Poly Lactic Acid	Microscope Obj :	Microscope Obj

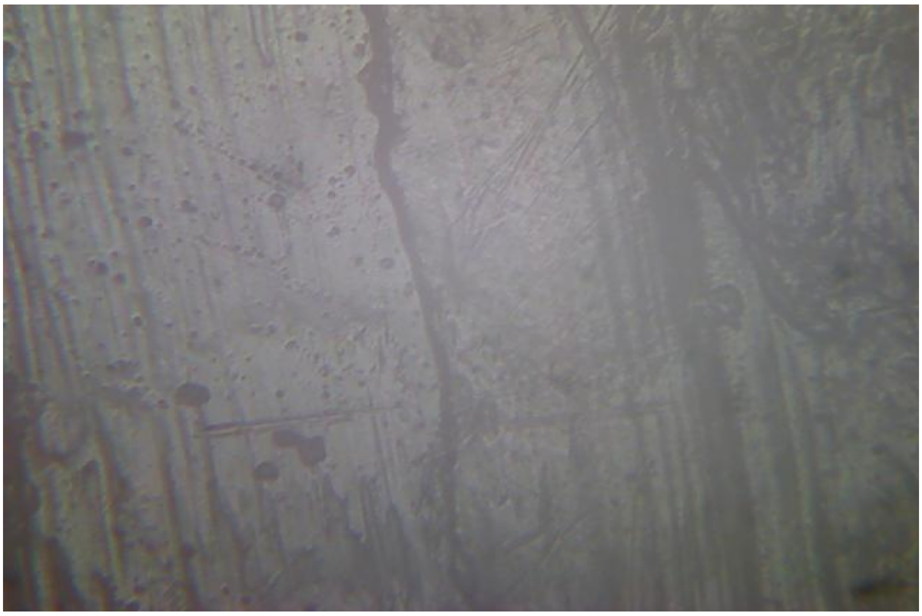


Figure 12. Micro-structure of PLA

Table 11. Porosity percentage of PLA

Unit : Micron

Field	Total	Pores %	Max. Peri	Min. Peri	Max. Area	Min. Area
Field 1	222	30.91	14173.4838	10.5263	589113.5734	6.9252

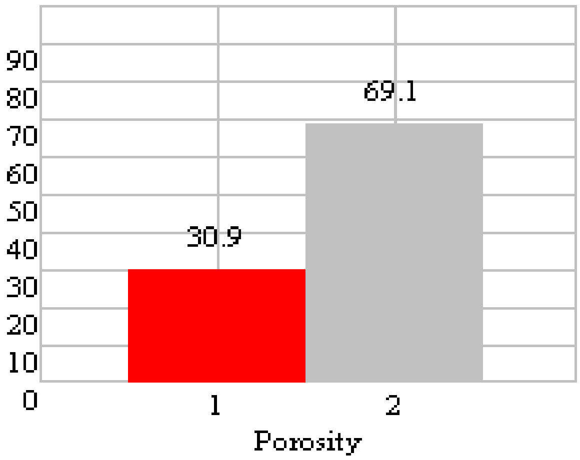
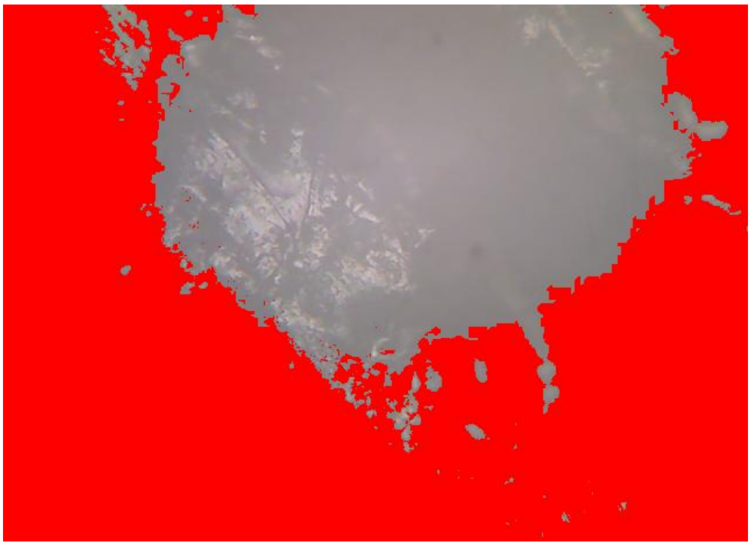
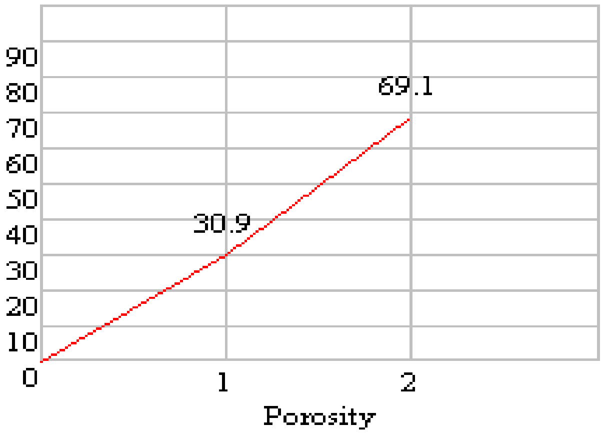


Figure 13. The graph between Porosity and Non-Porosity of PLA





From the work it is established that PLA is more useful than the Lay wood. Hence an extra test to know the composition of the material is done for PLA using X-ray Diffraction method(XRD).

Applications	Poly lactic acid
sequence	1 of 1
position	Large sample
Measurement time	19-march-2019 15:59:22

Compound	Si	p	s	cl	ca	ti
Concentration	6.321%	0.536%	0.712%	19.74%	19.06%	39.555%

compound	V	Mn	Fe	Co	Sn	Dy	Er

Concentration	0.456 %	0.118 %	1.441 %	0.00 %	1.319%	3.408%	7.345%

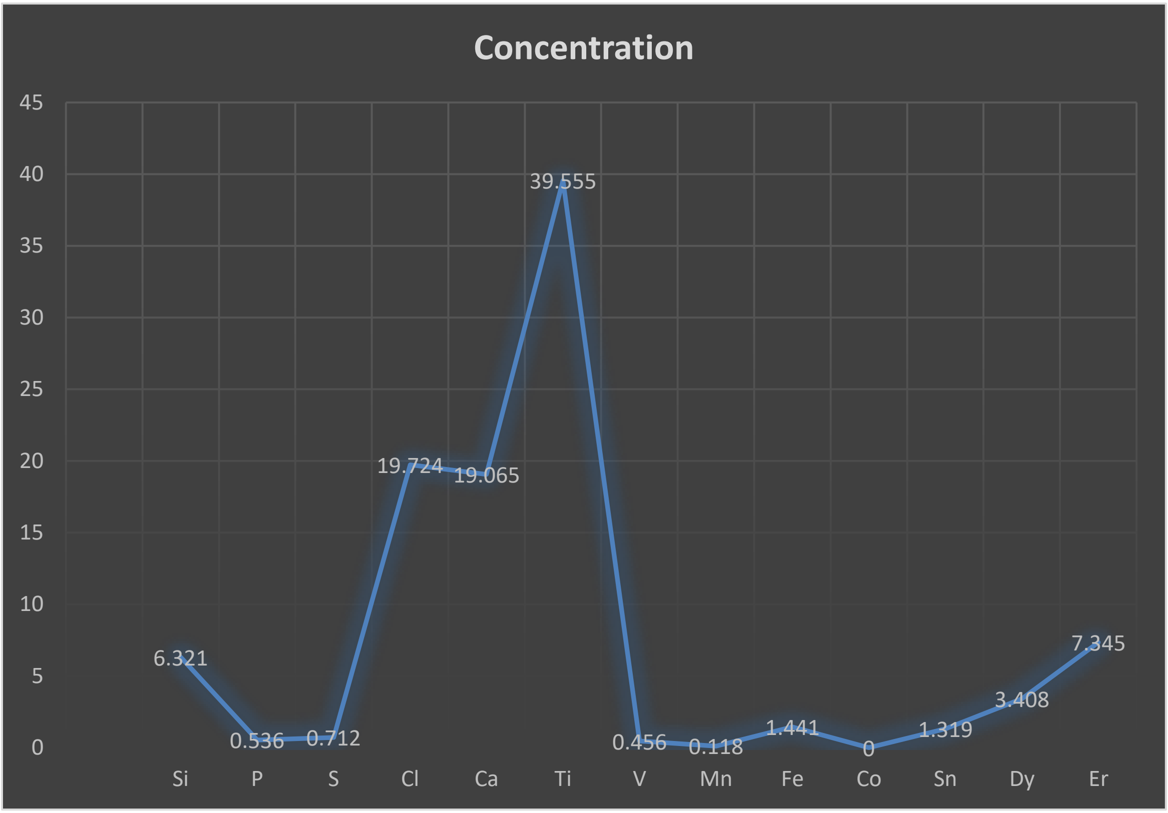


Figure 14. Peak point of composition in PLA material determined using XRD

CONCLUSION

In this work, the results of the mechanical properties of PLA and Lay Wood have been compared. The tensile strength of PLA is 42.9 N/mm^2 and for Lay wood is 29.6 N/mm^2 which is less than the tensile strength of PLA. The compressive strength is approximately similar with values for PLA 26 N/mm^2 and Lay wood 25.5 N/mm^2.The impact strength of these materials is nearly equal to zero and the hardness of Lay wood is less than the hardness of PLA with values for Lay wood as 80 and for PLA as 95. As the nodularity percentage is higher for both the materials, they are considered to be brittle and hard and the porosity of PLA is less than the Lay wood porosity which makes PLA surface smooth.

The results showed that PLA is more applicable than Lay wood because of its mechanical properties. From this work, it is found that both materials cannot be used in sudden load applications because their impact strength is nearly equal to 0.

It is also observed from this work that the PLA material does not need much post-processing before releasing into the market for surface finish because of less porosity.

In this way, this work is useful for predicting the mechanical properties of 3-D sprinting materials before making the objects in the industries. This work is very useful for managers and manufacturers of 3D printing materials.

REFERENCES

[1]. Lalit Singh Mehta, Dr.Priam Pillai, Compression Testing of PLA in 3D Printing, International Journal of Electronics, Electrical and Computational System, Vol 6, PP. 68-69, 2017.

[2]. Annamalai Pandian, Cameron Belavek, , American Society for Engineering Education, PP. 1-3,2016

[3]. Juraj Beniakl, Milos Matusi and Peter Krizan, Biodegradable Polymers for the Production of Prototypes, Vol 832, PP. 152-158, 2016

[4]. Martikka Ossi, Timo Karki and Qingling Wu, Mechanical Properties of 3D-Printed Wood-Plastic Composites, Trans Tech Publication, Vol 777, PP. 499-507, 2018

[5]. Durgun Ismail and Ertan Rukiye, Experimental investigation of FDM process for improvement of mechanical properties and production cost, Rapid Prototyping Journal, Vol. 20, PP. 228 - 235, 2014.

[6]. Tymrak B.M, Kreiger M, Pearce J.M, Mechanical Properties of components fabricated with open-source 3D printers under realistic environmental conditions, Vol 8, PP. 242-246, 2014.

[7]. Lee I and Kim Y, The Recent Patent Analysis and Industrial Trend of 3D Printing, Indian Journal of Science and Technology, Vol 8(S8), PP. 70-73, 2015 .

[8]. Godfrey C.Onwubolu and Farzad Rayegani, Characterization and Optimization of Mechanical Properties of ABS Parts Manufactured by the Fused Deposition Modelling Process, International Journal of Manufacturing Engineering, Vol 2014, PP. 13, 2014.

[9]. Es-Said O. S, Foyos J, Noorani R, Mendelson M, Marloth R & Pregger B.A, Effect of Layer Orientation on Mechanical Properties of Rapid Prototyped Samples, Vol 15, PP. 107-122, 2007.

[10]. Lee C.S, Kim S.G, Kim H.J, Ahn S.H, Measurement of anisotropic compressive strength of rapid prototyping parts, Journals of Materials Processing Technology,Vol 6, PP. 187-188, 2007.

[11]. Syed H. Masooda, Kalpesh kumar Maub, and Song W.Q, Tensile Properties of Processed FDM Polycarbonate Material, Tensile Properties of Processed FDM Polycarbonate Material, Vol 654-656, PP. 2556-2559, 2010.

[12]. Oksman S, Skrifvars M, Selin J, Natural fibres as reinforcement in poly lactic acid (PLA) composites, Composites Science & Technology, Vol 63, PP. 1317-1324, 2004.

[13]. Adam M. Pringle, Rudnicki Mark, and Joshua Pearce, Wood Furniture Waste-Based Recycled 3-D Printing Filament, Forest Products Journal, Vol 68, PP. 65-67, 2016.

[14]. Wang L, Gramlich WM, Gardner DJ, Improving the impact strength of Poly lactic acid (PLA) in fused layer modeling (FLM), Department Of Mechanical Engineering, Vol 4, PP 12-16, 2017.

[15]. Jianlei Wang, Hongmei Xie, Zixiang Weng, T.Senthil, Lixin Wu, A novel approach to improve mechanical properties of parts fabricated by fused deposition modeling, Department Of Manufacturing Engineering, Vol 7, PP. 23-26, 2016.