CHARACTERIZATION AND ANALYSIS OF MECHANICAL PROPERTIES FOR 3D PRINTING MATERIALS

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Abstract - *The recent developments in the 3D printing technology enables the digital manufacturing In mass-scale distribution and also the ready availability of 3D printers for the public at lowcostsand high mechanical properties makes the scientists to look at the properties of the 3Dprintingmaterials.However, to make 3D objects polymers are mainly used which generally have low mechanical properties. So, that there is an urgent need to charecterise and analyze the mechanical properties to assess which 3D printing materials have better properties. This work is aimed to find the best 3D printing material from existing materials. In this work, initially the mechanical properties of the 3D printing polymers like polylactic acid (PLA), Lay Wood have been analyzed. This work would propose the best 3D printing material from current basic 3D printing materials with improved mechanical properties.*

Key Words: **PLA, SLA, MJP, SOUP, SLS, CJP, LENS.**

1.INTRODUCTION

IMPORTANCE OF 3 D PRINTING: As the world is more advancing day by day given technology, the constraints like time, dimensional accuracy, surface finish etc are playing a major role in the industrial territory as the conventional machining process are not solving these problems. For ease in their life people are also looking into the production of the parts which are small in size and used often. As need and necessity leads to discovery, engineers looked into a manufacturing process called Additive Manufacturing to assure the needs of the people and industries

3D Printing is a process where physical objects are prepared by laying down many successive thin layers of material. It converts a digital data of the object into physical form by adding layer by layer of material. The basic principle behindthe3D Printing is additive manufacturing where objects are prepared by joining materials to make objects from 3D model data. Additive manufacturing technology which is a combination of many manufacturing process 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 the Rapid Prototyping where it is used to quickly fabricate a scale model of a physical part using three-dimensional CAD data.

TYPES:

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

1)Solid based AM

2)Liquid based AM

3)Powder based AM

1.1 SOLID BASED ADDITIVE MANUFACTURING:

The building material used in this type is in solid state. The solid form can include the shapes like wire, rolls, laminates and pellets (expect 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

1.2 LIQUID BASED ADDITIVE MANUFACTURING:

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

1) Stereo lithography Apparatus (SLA)

2) Multi-jet Printing (MJP)

3) Poly jet 3-D Printing

4) Solid Object Ultraviolet-Laser Printer (SOUP)

5) Rapid Freeze Prototyping

1.3POWDER BASED ADDITIVE MANUFACTURING: The building material used in this type is in powder state. 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) 9

4) Electron Beam Melting (EBM) etc.

2. 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 MPafor 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 [1].

Joshua M. Pearce et al (2003) studied on Rep Rap printed parts printed in realistic environmental conditions that can match and even perform commercial 3-Dprintersusing proprietary FDM in terms of tensile strength with the same polymers. Tensile strengths of the large sample set of Rep Rap prints fluctuated. This study determines the effect of color and processing temperature on material properties of Lulzbot TAZdeposited PLA in various colors. Five colors (white, black, blue, grey, and natural) of commercially available filament processed from 4043D PLA is tested for crystallinity with XRD, tensile strength following ASTM D638 and the micro-structure are done with environmental scanning electron microscope [2].

Lu Wang et al (2014) studied on 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 temperature was up to 114% higher than injection molded PLA made using conventional molding parameters [3].

Ossi Martikka1 et al (2018) studied on tensile properties and impact strength of two3D-printed commercial wood-plastic composite materials are studied and compared to those made of pure poly lactic acid. Relative to weight – mechanical properties and the effect of the amount of fill on the properties. This results indicate that parts made of 11 wood-plastic composites have notably lower tensile strength and impact strength that those made of pure poly lactic acid and mechanical properties can be considered sufficient for low-stress applications, such as visualization of prototypes and models or decorative items [4].

Cezary Grabowikl et al (2002) studied of tensile tests carried out for specimens made of the selected group of the filament materials. The selected group of the 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 way that ensures the best material characteristics. This research results allow to make comparison between a catalogue data and data obtained in the printing process [5].

TABLE NO-01: SPECIFICATONS 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℃ In normal state, max. 270℃
Support filaments	ABS/PLA/TPU and so on
Material diameter	1.75mm
Print speed	150mm/sec
File Format	G-Code, JPG, OBJ, STL
Host computer software	Cura
Other features	SD card off line printing function

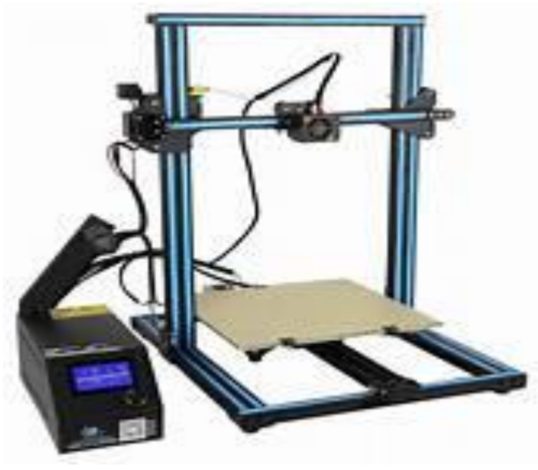


FIG 1: CREALITY 10-S 3-D PRINTER

RESULTS

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

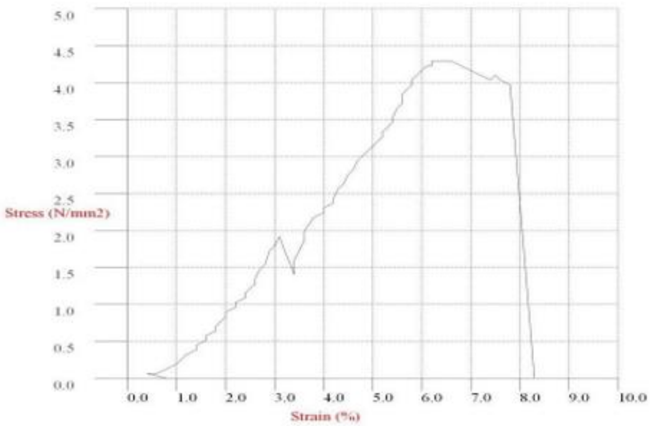
TABLE NO-2: TENSILE STRENGTH OF PLA

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

FIG NO-02: TENSILE SPECIMEN OF PLA AFTER THE TEST

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

TABLE NO-3: TABLE SHOWING TENSILE STRENGTH OF LAY WOOD



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 %
Lay wood	3.9	29.7	3.4	1.7	1.7	0.89

FIG NO-3: STRESS-STRAIN GRAPH OF PLA

And like the tensile strength, the compressive strength is also find out using Universal testing machine (UTM)

The compressive strength of PLA is given in the below table

TABLE NO-4: COMPRESSIVE STRENGTH AND IMPACT STRENGTH OF PLA

Name of the material	Compressive strength N/mm2	Impact strength N/mm2
PLA	26	1.8

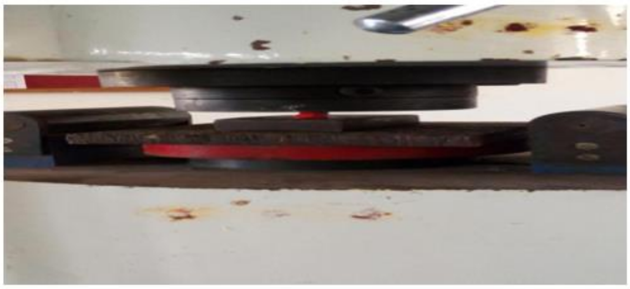


FIG NO-04: COMPRESSIVE STRENGTH TESTING OF PLA USING UTM

Lay wood compressive strength is given below in the table

TABLE NO-5: TABLE SHOWING COMPRESSIVE STRENGTH AND IMPACTSTRENGTH OF LAY WOOD

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

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

TABLE NO-6: TABLE SHOWING HARDNESS VALUES OF PLA

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

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

TABLE NO-7: TABLE SHOWING HARDNESS OF LAY WOOD

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

The result of nodularity for Lay wood is given in the below details

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

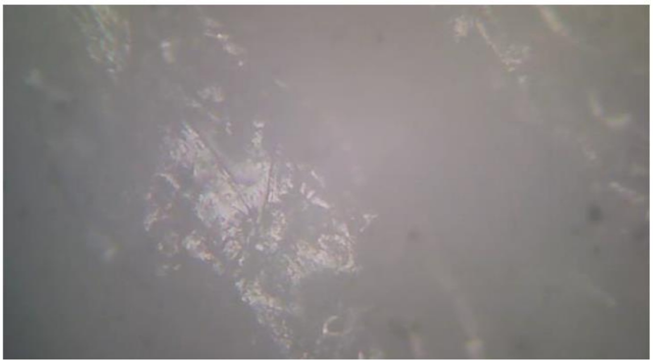
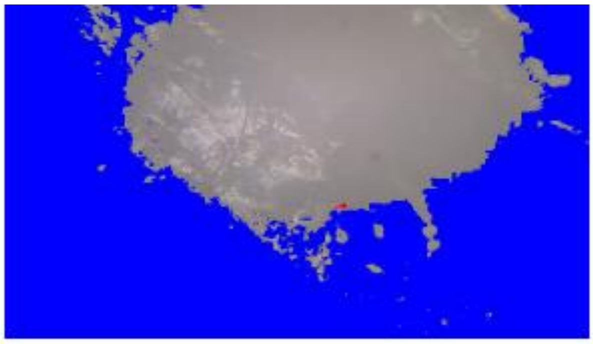


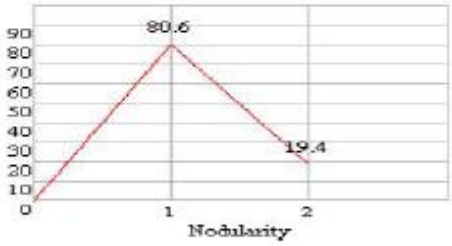
FIG NO-05: SHOWING THE MICROSTRUCTURE OF LAY WOOD MATERIAL

Unit : Micron

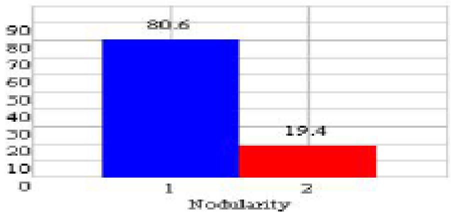
Field	Total	Nodule	Nodule %	per mm.sqr	Max Area	Min Area	Max Peri.	Min Peri.
Field 1	76	60	78.95	28.2031	1283795.014	6.925	11680.586	10.526

TABLE NO-8: SHOWING THE PERCENTAGE OF NODULARITY IN LAYWOOD





GRAPHS SHOWING THE VARIATION BETWEEN NODULARITY AND NONNODULARITY



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

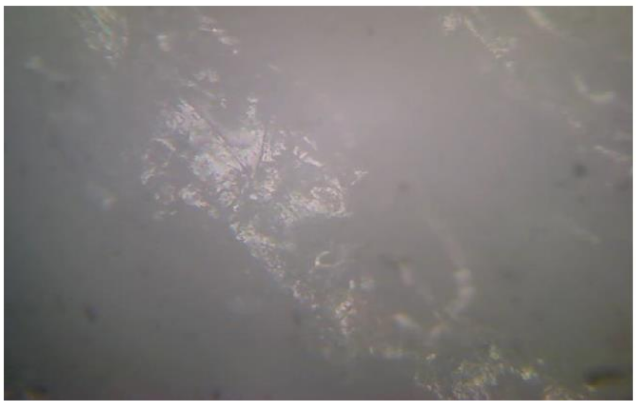
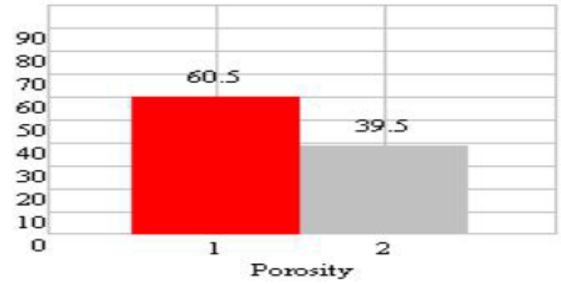


FIG NO-06: SHOWING THE MICRO STRUCTURE OF LAYWOOD

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

TABLE NO.9 TABLE GIVING THE POROSITY PERCENTAGE OF LAY WOOD



GRAPH BETWEEN POROSITY AND NON-POROSITY OF LAY WOOD

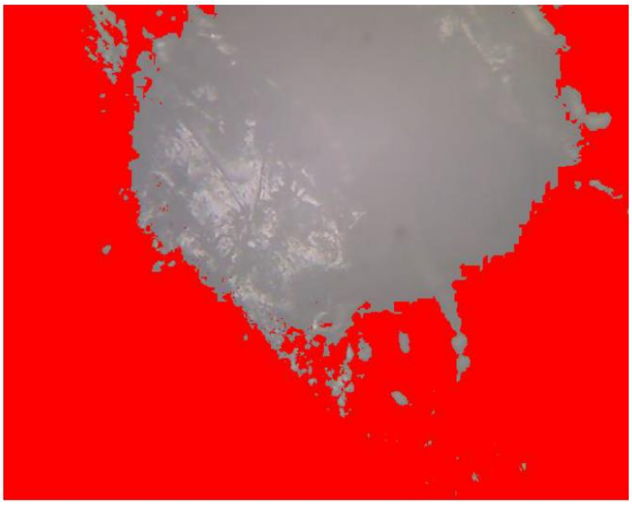
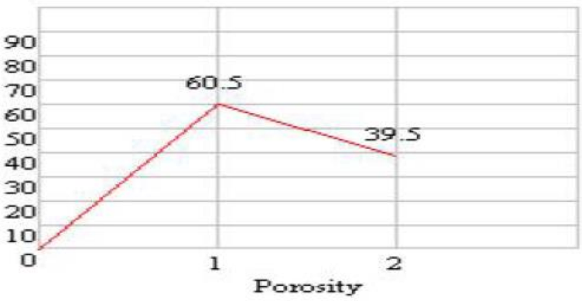


FIG NO-07: SHOWING THE MICRO STRUCTURE OF LAY WOOD AFTER FINDING POROSITY



The result of nodularity for PLA is given in the below details

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

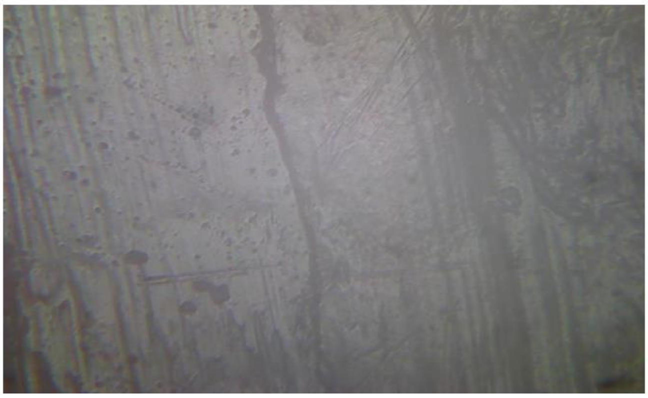
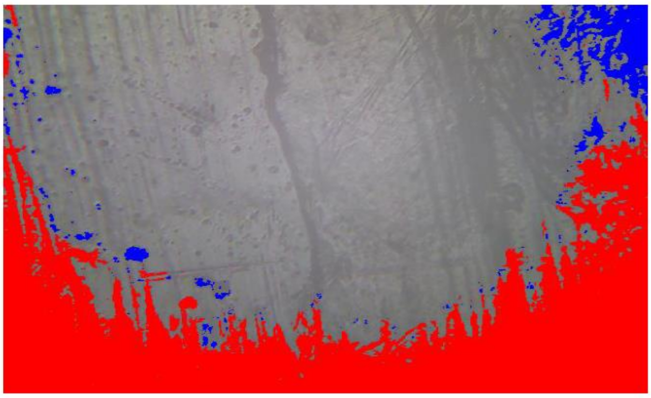


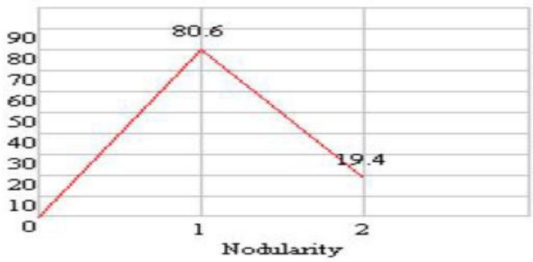
FIG NO-08: SHOWING THE MICROSTRUCTURE OF PLA MATERIAL

Unit : Micron

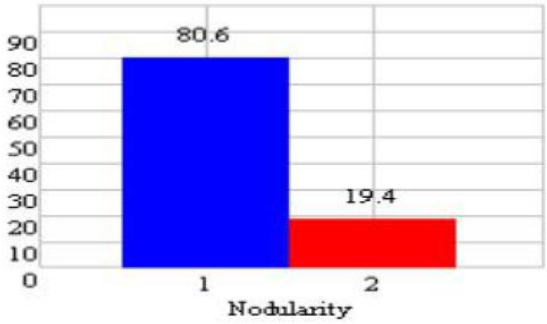
Field	Total	Nodule	Nodule %	per mm.sqr	Max Area	Min Area	Max Peri.	Min Peri.
Field 1	222	179	80.63	84.1393	40588.643	6.925	2550.179	10.526

TABLE NO-10: SHOWING THE PERCENTAGE OF NODULARITY IN PLA





GRAPHS SHOWING THE VARIATION BETWEEN NODULARITY AND NONNODULARITY



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

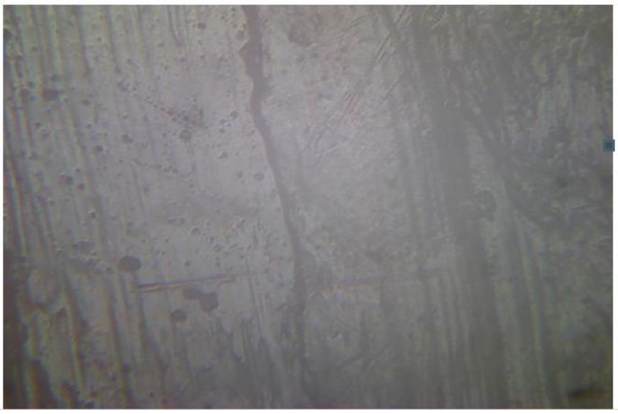
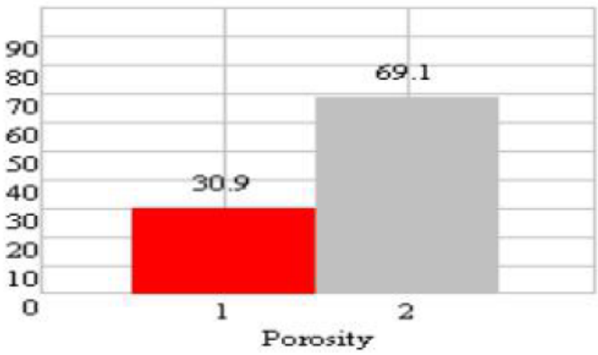


FIG NO-09: SHOWING THE MICRO STRUCTURE OF PLA

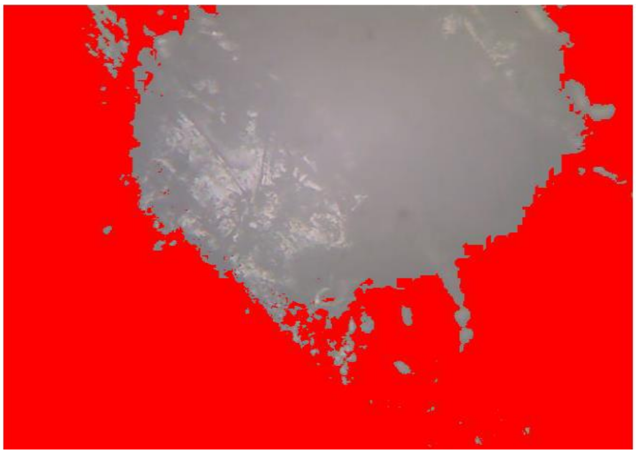
Unit : Micron

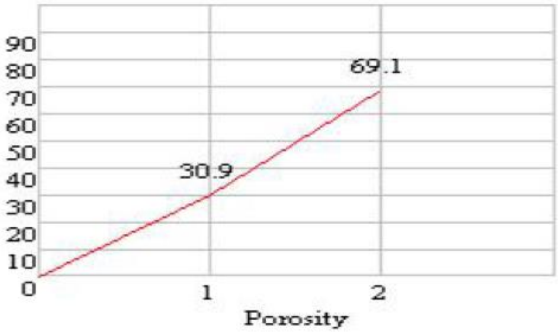
Field	Total	Pores %	Max. Peri	Min. Peri	Max. Area	Min. Area
Field 1	222	30.91	14173.4838	10.5263	589113.5734	6.9252

TABLE NO-11: TABLE GIVING THE POROSITY PERCENTAGE OF PLA



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
Concen. unit	6.321%	0.536%	0.712%	19.74%	19.06%	39.555%

compound	V	Mn	Fe	Co	Sn	Dy	Er
Concen. unit	0.456 %	0.118%	1.441 %	0.000 %	1.319%	3.408%	7.345%

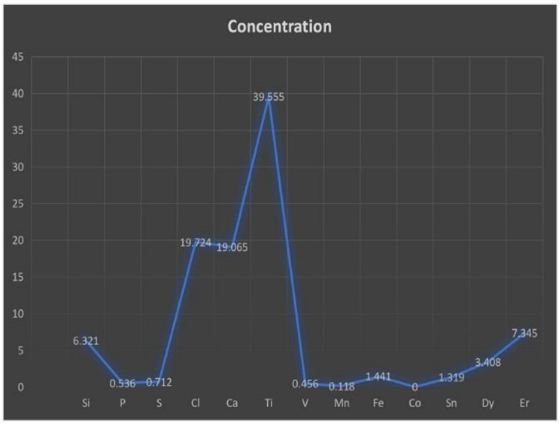


FIG NO:10 GRAPH SHOWING THE PEAK POINT OF COMPOSITION IN PLA MATERIAL DETERMINED USING XRD

3. CONCLUSIONS

In this work, results of the mechanical properties of PLA and Lay Wood have been compared. The tensile strength of PLA is 42.9 N/mm2 and for Lay wood is 29.6 N/mm2 which is less than the tensile strength of PLA. The compressive strength is approximately similar with values for PLA 26 N/mm2 and for Lay wood 25.5 N/mm2. The impact strength of these materials is nearly equal to zero and coming to the hardness Lay wood have less hardness than PLA with values for Lay wood it is 80 and for PLA it is 95. As the nodularity percentage is more for both the materials there are considered to be brittle and hard and porosity of PLA is less than the Lay wood porosity which makes PLA surface smooth.

The results showed that PLA is more applicable than the Lay wood because of its mechanical properties. From this work it is found that these both materials cannot be used in sudden load applications because of 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 market for surface finish because of less porosity.

In this way this work is useful for predicting the mechanical properties of 3D 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 3DPrinted 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.