Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 9 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

# Comparative Analysis of Mechanical Properties in 3D Printed PLA Dog Bone and Sandwich Structures via Additive Manufacturing

**Ikhrad Khan (Author)**
Department of Mechanical Engineering,
University of Engineering and Technology, Peshawar Pakistan.

**M. Faizan Khan (Corresponding Author)**
Department of Mechanical Engineering,
University of Engineering and Technology, Peshawar Pakistan.

## ABSTRACT

For comparative testing of ultimate tensile strength, flexural strength, hardness, and modulus of elasticity, dog-bone and sandwich structure specimens were 3D-printed using an entry-level MakerBot Replicator Mini+ and standard polylactic acid (PLA) material. Printing was performed under consistent parameters, including internal, external, and bed temperatures. The results showed that the sandwich structure's strength and modulus of elasticity were higher than the dog-bone's. Specifically, the flexural strength of the sandwich specimens (43–73 MPa) was greater than the tensile strength of the dog-bone specimens (38–55 MPa). Furthermore, the modulus of elasticity for the sandwich structures ranged from 1,800 to 3,600 MPa, a marked increase over the dog-bone specimens, which ranged from 950 to 1,250 MPa. In contrast, the dog-bone specimens showed greater hardness, with values of 50–165 HV, compared to the 70–100 HV range of the sandwich structures

**Key Words**- 3D Printer, PLA Material, Dog Bone Specimen, Sandwich Structure Specimen, Tensile Strength, Flexural Strength, Hardness HV

## Introduction

The increased affordability of 3D printers has made them accessible to a wide range of dedicated home users, with many high-quality, low-priced models now available [1]. Many of these consumer-level printers are marketed for use with polylactic acid (PLA) material, which is favored over acrylonitrile butadiene styrene (ABS) for several reasons [1]. PLA boasts superior strength, a lower melting temperature, and poses fewer health risks when printed in an open, room-temperature environment [1]. As a non-toxic, biodegradable material produced primarily from renewable resources, PLA is deemed safe for applications such as food packaging and the medical industry [1]. The primary drawback of PLA is its poor performance under load in warm conditions, where it tends to deform [1]. This balance of characteristics clarifies why

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 9 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

many manufacturers and engineers have focused on developing and promoting 3D printers that utilize PLA [1]. With the rise of at-home 3D printing, especially during the COVID-19 pandemic, public familiarity with this technology and its materials, like PLA, is expected to grow. Companies like MakerBot have already experienced significant sales, with over 15,000 units sold between 2009 and 2014 alone [3]. Extensive research has already been conducted on the material properties of PLA and ABS, as well as on printing parameters like speed and density. The purpose of this study is to investigate the properties of dog bone and sandwich structure specimens' 3D printed with PLA under specific conditions.

**3D Printer**

The process of 3D printing, also known as digital fabrication or additive manufacturing, involves creating three-dimensional objects by depositing material in successive layers based on a CAD (computer-aided design) model. Two common materials used in this technology are polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). The procedure for creating a 3D object generally follows three main steps [3].

**3D Modeling (CAD):** This initial phase involves designing the object in specialized software, such as SolidWorks, ProE, or AutoCAD. Since the printer requires specific instructions, creating an accurate digital model is essential. These modeling tools are widely used in various industries, including medical and dental, where laboratories design custom human body parts.

**Slicing the Model:** After the CAD model is created, it is processed by slicing software (e.g., MakerBot software). The CAD file is first converted into an STL format, which the slicing software can read. This program then digitally "slices" the model into thin horizontal layers, generating instructions for the 3D printer regarding the object's internal and external structure. These instructions are then sent to the printer for execution.

**3D Printing Deposition:** In the final step, the printer's nozzle receives the instructions from the slicing software. It then moves back and forth, dispensing melted material layer by layer. The printer waits for each layer to solidify before depositing the next, gradually building the three-dimensional object from the ground up [3].

**PLA Material**

Polylactic acid (PLA), also known as polylactide, is a thermoplastic material widely used as a 3D printing filament. It is formally produced through the condensation of lactic acid ($C_3H_6O_3$) during which water molecules are lost. Its derivation from renewable sources, such as corn starch and sugarcane, is a primary reason for its increasing popularity. As a bioplastic, PLA offers environmental benefits, including a reduced carbon footprint and biodegradability under industrial composting conditions. It is also designated as safe for medical devices, drug carriers, and food packaging within the human body due to its non-toxic nature. PLA is currently the most widely

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 9 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

used filament in 3D printing.
Some of the properties of PLA material are given in the following table

**Table 1:** PLA Material Properties

| *Properties of PLA Material* | *Units* | *Values in the range* |
|---|---|---|
| *Composition* | --- | PLA (Polylactic Resin) 98% — 99% |
| *Color* | --- | Green |
| *Diameter* | Mm | 1.70 — 1.78 |
| *Print Temperature* | °C | 190 — 230 |
| *Strength* | MPa | 13.72 — 108.00 |
| *Elongation at Break* | % | 4% —10% |
| *Modulus of Elasticity* | MPa | 343.24 — 3700 |
| *Hardness* | HV | 10 — 250 |
| *Density* | g/cm$^3$ | 1.21 — 1.25 |
| *Glass Temperature* | °C | 40 — 80 |
| *Melting Temperature* | °C | 150 — 180 |

**Experimental Procedure**

The ultimate tensile, flexural, elasticity, and hardness properties were investigated for two types of 3D-printed specimens: a dog bone specimen and a sandwich structure specimen. All specimens were fabricated from polylactic acid (PLA) material using a MakerBot Replicator Mini Plus. The fabrication process began by designing both specimens in SolidWorks and converting the models into stereolithographic (STL) files. Using these files, the 3D printer was initiated, and the printing parameters were set. To ensure uniformity, each specimen was printed separately, with consistent size and orientation. The variable printing parameters were speed and density, while size and orientation remained constant across all tests. Specifically, two density levels (75% and 95%) and four printing speeds (90, 110, 130, and 150 mm/s) were selected. The PLA filament was extruded at a temperature of 215°C, with a heated bed temperature of 65°C. All specimens were printed from 1-kg spools of PLA. To verify consistency, the size and orientation of each specimen were individually measured throughout the experimental procedure.

Mechanical tests were performed using an AG-IS SHEMADZU universal testing machine, which was used to determine the ultimate tensile strength, flexural strength, and modulus of elasticity. The machine's stroke speed was maintained at 50 mm/min. Hardness testing was conducted on a Micro Vickers hardness testing machine. All experiments were performed at room temperature.

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 9 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

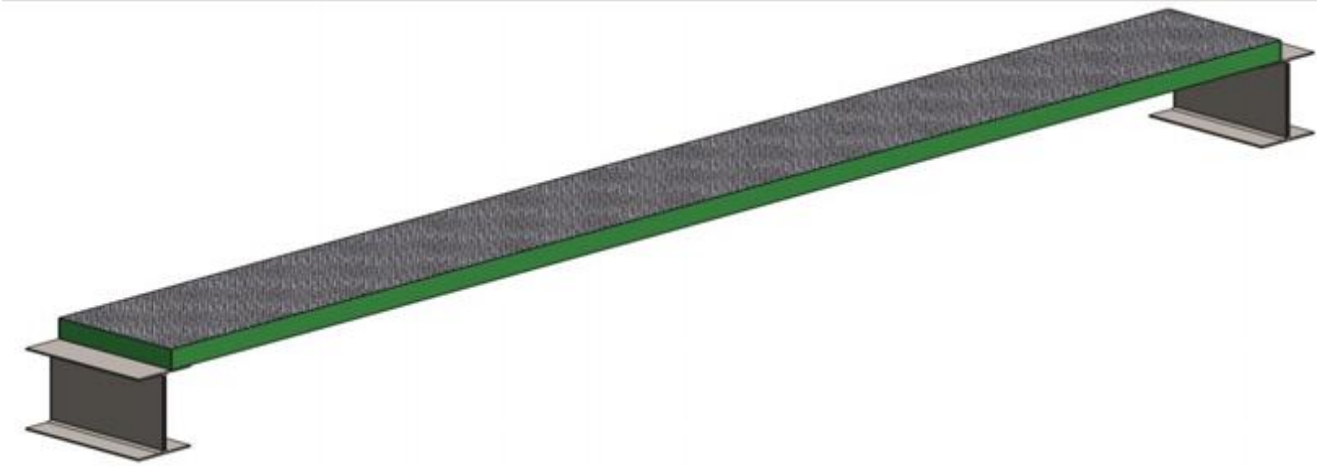


**Figure 1.** 3d-Printed Sandwich structure specimen Dimension [mm]




**Figure 2**: Schematic of Printed PLA Dog Bone Specimen and Standard Specimen Dimension
[mm]

**Ultimate Tensile and Flexural Testing of 3D Printed Specimen**

For the ultimate tensile and flexural testing, 16 specimens were prepared using polylactic acid (PLA), consisting of eight dog bone and eight sandwich structure samples. All tests were conducted on an AG-IS SHEMADZU universal testing machine (UTM). During the tests, the UTM's wedge grips were displaced at a constant rate of 50 mm/min, with data on applied force, displacement, and elongation collected at 100 Hz. The UTM directly measured the force, strain, and tensile strength and flexural strength values. A total of 16 specimens were tested under varying printing speeds and densities. To ensure consistency for the calculation of tensile strength, all specimens were fabricated with identical length, width, and thickness dimensions, allowing for the measurement of only a single specimen.

**Hardness Testing of 3D Printed Specimen**

A Micro Vickers hardness testing machine was used to determine the hardness of sixteen 3D-printed specimens, comprising both dog bone and sandwich structures. The specimens were tested under varying printing speeds and densities. A constant force of 1 kgf was applied to each specimen for a dwell time of 5 seconds. The machine's high-resolution electronic microscope was used to measure the deformed surface. Microscopic deformations, recorded as diagonal lengths (L1 and L2) in

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 9 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

millimeters, were converted to micrometers for accurate calculation, as the test measures very small surface deformations. Hardness was calculated using the formula.

Hardness = $1.854 \times F/D^2$

Where F is the applied force and D is the average diagonal length.

## Results

### Ultimate Tensile and Flexural Testing of 3D Printed Specimens

Eight specimens of dog bone were tested and eight specimens of sandwich structure specimens were tested having same length, width and thickness. The following tables shows the individual result of each specimen.

**Table 2:** Tensile Testing Data for Dog Bone Specimens

| Printing speed (mm/s) | Density percentage (%) | Force (N) | Tensile Strength (MPa) |
|---|---|---|---|
| 90 | 75 | 1550.40 | 44.52 |
| 110 | 75 | 1189.06 | 39.63 |
| 130 | 75 | 1200.00 | 39.99 |
| 150 | 75 | 1148.43 | 38.27 |
| 90 | 95 | 1615.62 | 53.85 |
| 110 | 95 | 1567.19 | 52.23 |
| 130 | 95 | 1487.50 | 52.97 |
| 150 | 95 | 1607.81 | 53.59 |

**Table 3:** Flexural Testing Data for Sandwich Structure Specimens

| Printing speed (mm/s) | Density percentage (%) | Force (N) | Flexural Strength (MPa) |
|---|---|---|---|
| 90 | 75 | 1446.92 | 50.22 |
| 110 | 75 | 1324.77 | 46.69 |
| 130 | 75 | 1350.00 | 44.37 |
| 150 | 75 | 1292.18 | 43.92 |
| 90 | 95 | 1815.42 | 72.65 |

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 9 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

| | | | |
|---|---|---|---|
| 110 | 95 | 1767.09 | 71.74 |
| 130 | 95 | 1687.70 | 71.84 |
| 150 | 95 | 1807.64 | 72.98 |

In case of density, the flexural strength of sandwich structure specimen is greater than that of tensile strength of dog bone specimen. The tensile strength of dog bone specimen was in the range of 38 MPa to 55 MPa, while the flexural strength of sandwich structure specimen was in the range of 43 MPa to 73 MPa. Similarly, in case of printing speeds, the tensile strength of dog bone specimen decreases when the printing speed increases, and the same case happened in sandwich structure specimen also.

**Table 4:** Modulus od Elasticity Data for Dog Bone Specimen

| **Printing speed (mm/s)** | **Density percentage (%)** | **Modulus of Elasticity (MPa)** |
|---|---|---|
| 90 | 75 | 1029.73 |
| 110 | 75 | 977.46 |
| 130 | 75 | 1019.92 |
| 150 | 75 | 1100.00 |
| 90 | 95 | 1176.84 |
| 110 | 95 | 1164.66 |
| 130 | 95 | 1109.00 |
| 150 | 95 | 1187.00 |

**Table 5:** Modulus od Elasticity Data for Sandwich Structure Specimen

| **Printing speed (mm/s)** | **Density percentage (%)** | **Modulus of Elasticity (MPa)** |
|---|---|---|
| 90 | 75 | 1872.33 |
| 110 | 75 | 2115.00 |
| 130 | 75 | 2248.66 |
| 150 | 75 | 2316.89 |

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 9 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

| | | |
|---|---|---|
| 90 | 95 | 2920.00 |
| 110 | 95 | 3001.12 |
| 130 | 95 | 3216.29 |
| 150 | 95 | 3589.99 |

In case of density, the modulus of elasticity of dog bone specimen were in the range of 950 MPa to 1250 MPa, while the modulus of elasticity for sandwich structure specimen were in the range of 1800 MPa to 3600 MPa. Similarly, the modulus of elasticity for both specimens increases when the printing speed increases.

**Hardness Testing of 3D Printed Specimen**

Eight specimens of dog bone specimens and eight specimens of sandwich structure specimens were printed and tested at each printing speed and its specified density. For this testing, a very low deformation was considered which we can measure it with the help of microscope. In some specimen the diagonal length was very low while in some specimens the diagonal length was high because of threads on the surface of specimens. The following tables shows the individual results for each test and specimen. Table 6 and table 7 shows the hardness testing date for dog bone specimens and sandwich structure specimens.

**Table 6:** Hardness testing data of Dog Bone specimens

| **Printing speed (mm/s)** | **Density (%)** | **Hardness (HV)** |
|---|---|---|
| 90 | 75 | 51.31 |
| 110 | 75 | 65.2 |
| 130 | 75 | 79.25 |
| 150 | 75 | 120.82 |
| 90 | 95 | 61.7 |
| 110 | 95 | 71.6 |
| 130 | 95 | 91.35 |
| 150 | 95 | 162.85 |

**Table 7:** Hardness testing data of Sandwich specimens

| **Printing speed (mm/s)** | **Density (%)** | **Hardness (HV)** |
|---|---|---|
| 90 | 75 | 70.81 |
| 110 | 75 | 75.44 |
| 130 | 75 | 89.31 |
| 150 | 75 | 95.12 |

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 9 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

| | | |
|---|---|---|
| 90 | 95 | 84.18 |
| 110 | 95 | 89.65 |
| 130 | 95 | 94.04 |
| 150 | 95 | 98.95 |

For PLA 3d printed dog bone specimen, the 95% density specimens produced the hardest specimens as compared to the 75% density specimens and its hardness values were in the range of 50 HV to 165 HV. When we look at the above table 6 the 95% density specimens produced the hardest specimens while 75% density specimens' hardness values were less than 95% density specimens.
While when we look at the table 6, when the printing speed increases from 90mm/s to 150mm/s the hardness also increases for specific densities.
Similarly, for 3d printed sandwich structure specimen, the 95% density specimens produced the hardest specimens as compared to the 75% density specimens and its hardness values were in the range of 70 HV to 100 HV. When we look at the above table 7 the 95% density specimens produced the hardest specimens while 75% density specimens' hardness values were less than 95% density specimens. While when we look at the table 7, when the printing speed increases from 90mm/s to 150mm/s the hardness also increases for specific densities.

## Conclusion

The mechanical properties of PLA 3D-printed dog bone and sandwich structure specimens were evaluated through tensile, flexural, and hardness testing. For tensile and flexural properties, the sandwich structure specimens demonstrated higher flexural strength than the tensile strength of the dog bone specimens. This indicates that the sandwich structures have a greater load-bearing capacity. Similarly, the sandwich structures exhibited a higher modulus of elasticity compared to the dog bone specimens. In hardness testing, results showed that hardness increased with both printing speed and density. The highest hardness values were observed in specimens with a 95% density and a printing speed of 150 mm/s. A comparative analysis of specimen types revealed that the dog bone specimens consistently had a higher hardness range than the sandwich structure specimens.

## References

Ikhrad Khan, Naveedullah, "Fabrication and Characterization of Standard 3D-Printed Specimen under Various Printing Speeds and Infill Densities" Vol. 03, Issue No. 9 (2025), Annual Methodological Achieve Research Review (AMARR).

Todd Letcher, Megan Waytashek. "Material Property Testing of 3D-Printed Specimen in PLA, on an Entry-Level 3D Printer", Volume 2A: Advanced Manufacturing, 2014

Stephens, B., Azimi, P., El Orch, Z., Ramos, T.Ultrafine particle emission from desktop 3D printers Atmospheric Environment, Volume 79, November 2013, pages 334-339

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 9 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Rodrigues JF, Thomas JP, Renard JE. Design of fused deposition ABS components for stiffness and strength journal of Mechanical Design 2003, Vol 125(3): Pages 545-551.

Li L, Sun Q, bellehumeur C, Gu P. composite modeling and analysis for fabrication of FDM prototypes with locally controlled properties. Journal of Manufacturing Processes 2002, Vol 4(2), pages 129-141

Ahm SH, Montero M, Odell D, Roundy S, Wright PK. Anisotropic material properties of fused deposition modeling ABS. Rapid Prototyping journal 2002 Vol 8(4), pages 248-257

L. Bade, P.M. Hackney, I. Shyha, M. Birkett. Faculty of Engineering and Environment, Northambia University at Newcastle. Journal of Procedia Engineering 2015, Vol 132, Pages 86-93

Bellini A, Giceri S. Mechnical characterization of parts fabricated using fused deposition modeling. Rapid Prototyping Journal 2003 Vol 9(4), pages 252-264

Rodriguez JF, Thomas JP, Renaud JE. Mechanical behavior of acrylonitrile butadiene styrene (ABS) fused deposition materials. Experimental Investigation Rapid Prototyping Journal 2001, Vol 7(3), pages 148-158

Sood AK, Ohdar RK, Mahapatra SS. Parametric Appraisal of mechanical parts. Material Design, 2010, Vol 31(1), P 287-295

Rishabh Sood, Sharad K. Pradhan. "Design and development of a low-cost open-source 3D printer and its single response optimization using polylactic acid (PLA) material", Materials Today: Proceedings, 2020

ASTM Standard D638, 2010, “Standard test method for tensile properties of plastics”. ASTM International, West Conshohocken, PA, 2010

Mohd A. Salim, Zarif H. Termiti, Adzni Md. Saad. "Mechanical Properties on ABS/PLA Materials for Geospatial Imaging Printed Product using 3D Printer Technology", Elsevier BV, 2019.

V. Harshitha, Seeram Srinivasa Rao. "Design and analysis of ISO standard bolt and nut in FDM 3D printer using PLA and ABS materials", Materials Today: Proceedings, 2019

Ieva Gendviliene, Egidijus Simoliunas, Sima Rekstyte, Mangirdas Malinauskas et al. "Assessment of the morphology and dimensional accuracy of 3D printed PLA and PLA/HAP scaffolds", Journal of the Mechanical Behavior of Biomedical Materials, 2020.