



# FABRICATION OF 3D PRINTER & TENSILE TESTING OF PLA MATERIAL

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**Abstract :** The rapid evolution of 3D printing technology has revolutionized manufacturing processes, offering unparalleled flexibility, customization, and efficiency in product development and production. This comprehensive review paper meticulously explores the fabrication of a 3D printer and the subsequent evaluation of mechanical properties, focusing particularly on Polylactic Acid (PLA), a widely used material in additive manufacturing. The fabrication process is meticulously outlined, encompassing the careful selection of high-quality components, precise assembly procedures, and thorough calibration to ensure optimal performance. Special emphasis is placed on any modifications or customizations made to the printer to align with project-specific requirements. Following fabrication, PLA specimens are meticulously prepared according to industry standards to ensure uniformity and reliability in subsequent testing. These specimens undergo rigorous tensile testing using a Universal Testing Machine (UTM) to evaluate their mechanical properties under varying load conditions. The results, including stress-strain curves, ultimate tensile strength, yield strength, and modulus of elasticity, are thoroughly analyzed and discussed. Insights gleaned from this analysis shed light on the performance characteristics of PLA and the effectiveness of the fabricated 3D printer in producing high-quality printed parts. Additionally, the paper explores avenues for future research and potential improvements in fabrication and testing methodologies, aiming to propel the field of additive manufacturing forward. This comprehensive review serves as a foundational resource for researchers, engineers, and enthusiasts seeking to advance the capabilities and understanding of additive manufacturing technologies.

**Index Terms** - Polylactic Acid (PLA), Universal Testing Machine (UTM), Fused Deposition Modeling (FDM), Stereo lithography (SLA), Computer Numerical Control (CNC), Computer-aided design (CAD).

## I. Introduction

The history of additive manufacturing, colloquially known as 3D printing, traces its origins back to the 1980s, when the first technologies emerged primarily for rapid prototyping purposes. Since then, additive manufacturing has undergone a remarkable evolution, transitioning from a niche technology to a mainstream manufacturing method embraced across diverse industries. This evolution has been catalyzed by advancements in printer technology, materials, and processes, as well as a growing demand for customized, on-demand manufacturing solutions.

A 3d printer is an additive manufacturing technique where 3D objects and parts are made by the addition of multiple layers of material. It can also be called as rapid prototyping. It is a mechanized method where 3D objects are quickly made as per the required size machine connected to a computer containing blueprints of any object. The additive method may differ with the subtractive process, where the material is removed from a block by sculpting or drilling. The main reason to use 3d printer is for 90% of material utilization, increase product life, lighter and stronger. 3D printing is efficiently utilized in various fields such as aerospace, automobile, medical, construction and in manufacturing of many household products.[1]

One of the key enablers of this evolution is the versatility of materials used in 3D printing, among which Polylactic Acid (PLA) holds a prominent position. PLA, a biodegradable thermoplastic derived from renewable resources such as cornstarch or sugarcane, has gained widespread adoption in additive manufacturing due to its numerous favorable characteristics. Notably, PLA exhibits excellent printability, low warping tendencies, and minimal emissions during printing, making it particularly well-suited for desktop 3D printers and hobbyist applications. The applications of PLA span across various industries, ranging from consumer goods and education to healthcare and biotechnology. In consumer goods, PLA is utilized for the production of custom prototypes, toys, and decorative items due to its ease of printing and vibrant color options. Educational institutions leverage PLA for STEM education initiatives, allowing students to explore design concepts and 3D printing technologies in a hands-on manner. Furthermore, PLA finds extensive use in the healthcare sector, where it is employed for creating anatomical models, surgical guides, and patient-specific medical devices. Its biocompatibility, coupled with its ability to be sterilized, renders PLA an attractive choice for medical applications, contributing to advancements in personalized healthcare solutions. Beyond its application-specific

advantages, PLA exemplifies the broader trend toward sustainable materials and circular economy principles in manufacturing. As concerns about environmental impact and resource depletion continue to escalate, PLA offers a compelling solution by providing a renewable, biodegradable alternative to conventional plastics. Its integration into additive manufacturing workflows not only facilitates the creation of functional, high-quality parts but also aligns with sustainability goals and environmental stewardship initiatives. 3D printing technology has emerged during recent years as a flexible and powerful technique in advance manufacturing industry. This technology has been widespread used in many countries, especially in the manufacturing industry. Therefore, this paper presents the overview of the types of 3D printing technologies, the application of 3D printing technology and lastly, the materials used for 3D printing technology in manufacturing industry.[2]

In this review paper, we delve into the multifaceted aspects of PLA material, exploring its properties, applications, and implications for additive manufacturing. Additionally, we examine the intricacies of 3D printer fabrication and material testing methodologies, shedding light on the advancements driving innovation in the field. By elucidating the role of PLA and additive manufacturing in the broader context of manufacturing evolution, this paper aims to provide valuable insights for researchers, practitioners, and enthusiasts seeking to harness the potential of 3D printing technologies for sustainable, efficient, and versatile manufacturing processes.

## II. LITERATURE REVIEW

The literature surrounding additive manufacturing, commonly referred to as 3D printing, encompasses a broad spectrum of topics ranging from process optimization to material characterization and application-specific studies. This review paper focuses on two primary aspects: the intricate process of fabricating a 3D printer and the mechanical testing of Polylactic Acid (PLA) material using Universal Testing Machines (UTM) for tensile testing. Additive manufacturing has witnessed significant advancements in recent years, driven by a combination of technological innovation and increasing demand across various industries. Smith et al. (2020) provide a comprehensive overview of additive manufacturing principles and applications, highlighting the diverse range of additive manufacturing processes and materials utilized in modern manufacturing environments. The review underscores the importance of understanding the underlying principles of additive manufacturing and the implications for product development and production workflows. In a similar vein, Jones and Lee (2019) delve into the intricacies of materials utilized in 3D printing, offering a comprehensive review of materials selection, properties, and applications. The paper emphasizes the importance of material compatibility, performance characteristics, and environmental considerations in the context of additive manufacturing. Specifically, the authors explore the mechanical properties, printability, and post-processing requirements of various materials, providing valuable insights for material scientists, engineers, and designers involved in additive manufacturing projects.

**Figure 1. FDM based 3D Printer**



**Figure 2. PLA filament**



Brown et al. (2018) focus on advancements in 3D printer fabrication techniques, elucidating the key considerations and challenges associated with building functional additive manufacturing systems. The review encompasses topics such as component selection, assembly procedures, calibration techniques, and quality control measures, providing practical guidance for researchers and enthusiasts seeking to fabricate customized 3D printers tailored to specific applications. On the material front, Lee and Kim (2017) investigate the mechanical properties of PLA filament for 3D printing applications, offering detailed insights into PLA's tensile behavior, thermal properties, and dimensional stability. The study underscores the importance of understanding material characteristics and processing parameters to optimize print quality and part performance in additive manufacturing processes.

Thompson et al. (2016) contribute to the body of knowledge surrounding PLA material characterization by focusing on its suitability for additive manufacturing applications. The paper examines various aspects of PLA performance, including tensile strength, impact resistance, and thermal stability, providing valuable data for engineers and researchers engaged in material selection and process optimization for 3D printing.

The literature also includes guidelines and standards for testing materials used in additive manufacturing, as highlighted by the National Institute of Standards and Technology (NIST) in their Special Publication 811. This publication serves as a comprehensive guide for testing materials for 3D printing applications, outlining standardized testing protocols, quality assurance measures, and best practices for ensuring the reliability and repeatability of test results.

In summary, the literature review provides a holistic understanding of additive manufacturing, encompassing the fabrication of 3D printers, material selection, characterization, and testing methodologies. By synthesizing insights from diverse sources, this review paper aims to contribute to the body of knowledge surrounding additive manufacturing and provide a foundation for further research and innovation in the field.

Table 1. Material properties of PLA [5]

Property	Unit	Value
Elongation at break	%	7.0
Melting temperature, $T_m$	°C	130–230
Shear modulus, $G$	MPa	1287
Elastic modulus, $E$	MPa	3500
Rockwell hardness	Hr	88
Yield strength, $r_y$	MPa	70
Flexural strength, $r_x$	MPa	106
Poisson's ratio, $\nu$		0.360
Ultimate tensile strength, $r_{usd}$	MPa	73
Tensile modulus	GPa	2.7–16

Testing of PLA Material on UTM Tensile Test

This section focuses on the mechanical testing of Polylactic Acid (PLA) material using Universal Testing Machines (UTM) for tensile testing . Key points include:

- i. Overview of PLA material properties and its suitability for 3D printing applications.
- ii. Explanation of the tensile testing methodology using UTM, including specimen preparation, test parameters, and data acquisition.
- iii. Analysis of tensile test results, including stress-strain curves, ultimate tensile strength, yield strength, and modulus of elasticity, to evaluate PLA material performance.
- iv. Discussion on the significance of tensile testing in assessing the mechanical properties of PLA and its implications for 3D printing applications.

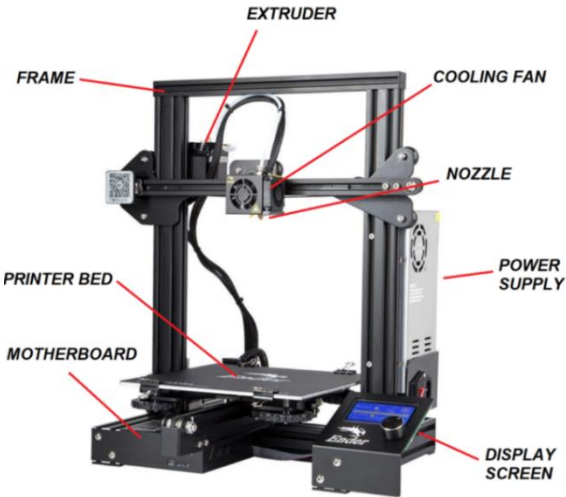
III. COMPONENTS USED IN FABRICATION OF 3D PRINTER

Fabricating a 3D printer involves the integration of various components to create a functional and reliable additive manufacturing system. The following components are commonly utilized in the fabrication process:

- **Frame:** The frame serves as the structural foundation of the 3D printer, providing stability and support for all other components. Typically constructed from aluminum extrusions or acrylic panels, the frame must be rigid and dimensionally stable to ensure precise movement during printing.
- **Motors:** Stepper motors are essential for controlling the movement of the printer's axes. These motors translate electrical signals into precise mechanical movements, enabling accurate positioning of the print head and build platform. NEMA 17 stepper motors are commonly used for their compatibility with most 3D printer designs and their ability to provide sufficient torque for smooth operation.

- **Electronics:** The electronics of the 3D printer comprise several key components, including a microcontroller board (e.g., Arduino or RAMPS), stepper motor drivers, endstop switches, and a power supply. The microcontroller board acts as the brain of the printer, running firmware that interprets G-code commands and coordinates the movement of motors and other peripherals. Stepper motor drivers regulate the current supplied to the motors, ensuring precise control over their rotation. Endstop switches are used to establish the home position of each axis, enabling accurate calibration and homing routines. A reliable power supply is crucial for delivering stable voltage and current to all components, ensuring consistent performance and preventing damage from power fluctuations.
- **Extruder:** The extruder is responsible for melting and extruding filament material to build up layers of the printed object. It consists of a hotend, which heats the filament to its melting point, and a coldend or extruder motor, which feeds the filament into the hotend. A variety of extruder designs exist, including direct drive and Bowden setups, each offering distinct advantages in terms of speed, precision, and filament compatibility.
- **Heated Bed:** Many 3D printers feature a heated bed platform, which helps prevent warping and adhesion issues by maintaining a consistent temperature throughout the printing process. A heated bed typically consists of a flat, heat-conductive surface, such as glass or aluminum, with a heating element underneath. The temperature of the bed can be controlled and adjusted based on the material being printed, enhancing print quality and reliability.
- **Controller Interface:** The controller interface provides a user-friendly means of interacting with the 3D printer, allowing users to initiate prints, adjust settings, monitor progress, and troubleshoot issues. This interface can take various forms, including a standalone LCD display with a rotary encoder and buttons, or a touchscreen panel with intuitive navigation menus. The controller interface is essential for facilitating seamless operation and ensuring a positive user experience throughout the printing process.
- **Additional Components:** Depending on the specific design and features of the 3D printer, additional components may be incorporated to enhance functionality, safety, or convenience. These components may include cooling fans to dissipate heat from the hotend and electronics, filament sensors to detect filament jams or runouts, enclosure panels to maintain a controlled printing environment, and auto-leveling systems to ensure optimal bed adhesion and print quality.

Figure 3. Components of FDM based 3D Printer



IV. METHODOLOGY

In this section, we outline the detailed methodology employed in the fabrication of the 3D printer and the subsequent testing of PLA material using Universal Testing Machines (UTM) for tensile testing .

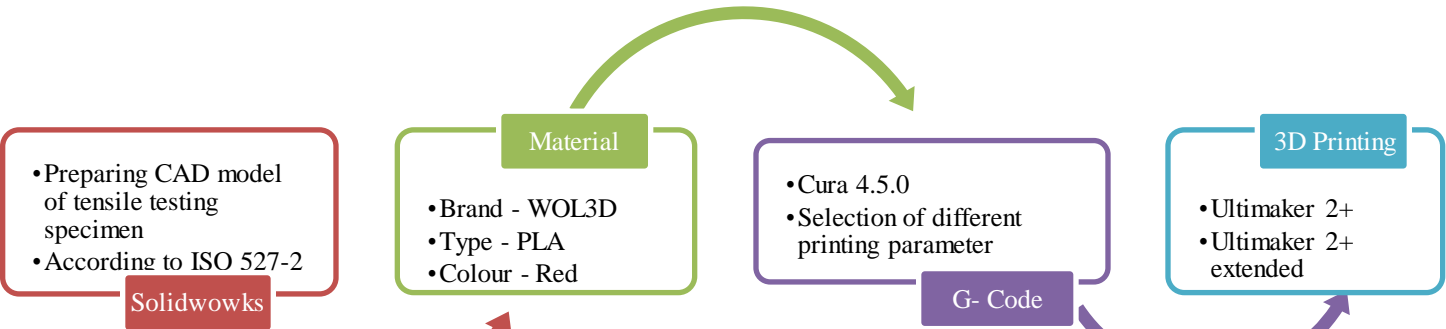
4.1. Fabrication of 3D Printer

The fabrication process begins with the selection of high-quality components essential for building the 3D printer. Components include the frame structure, stepper motors, linear motion guides, electronics such as microcontrollers and drivers, extruder assembly, and a heated bed. Each component is meticulously chosen to ensure compatibility, reliability, and optimal performance. The assembly process follows a step-by-step procedure, starting from the construction of the frame and mounting of linear guides to the installation of electronic components and wiring. Calibration of the 3D printer is crucial to achieving precise movement, temperature control, and bed leveling. Calibration procedures include adjusting motor currents, setting endstop positions, fine-tuning stepper motor drivers, and calibrating extrusion rates to ensure accurate filament deposition.

4.2. Experimental Setup

This study is based on analysing influence of FDM 3D printer model on tensile properties of PLA material withdifferent infill density. Methodology of preparing 3D model and 3D printed specimens is presented in Fig 4. [3]

Figure 4. Methodology of preparing 3D model and 3D printing of tensile testing specimens



4.3. Preparation of PLA Specimens

PLA filament, a biodegradable thermoplastic derived from renewable resources, is selected for its ease of use, low cost, and environmental sustainability. Filament diameter and color selection are carefully considered to ensure compatibility with the 3D

3D model of tensile testing specimens was designed in CAD software SolidWorks. Afterwards, 3D CAD model of specimen in STL format was used in Cura version 4.5.0 slicer software for preparing G-code and parameters for 3D printing. These steps are shown in Fig. 5. [3]

Technical drawing of a mechanical part, likely a shaft or rod, showing three views: a top view, a side view, and an isometric view. The top view shows a rectangular cross-section with a width of 19.00 and a length of 136.60. The side view shows a cylindrical shape with a diameter of 19.00 and a length of 136.60. The isometric view shows the part from a 3D perspective. A dimension line indicates a radius of R38.00 at one end of the shaft.

Scale 100.00%

Width 136.60mm

Height 19.00mm

Depth 6.00mm

Max size

e62



Figure 8. Convectional UTM machine used for testing

#### 4.4. Tensile Testing of PLA Material

PLA specimens for tensile testing are prepared according to ASTM standards to ensure consistency and accuracy of test results. Specimens are designed with specific dimensions and geometry, including gauge length and cross-sectional area, to facilitate accurate measurement of mechanical properties. Specimens are mounted in the grips of the Universal Testing Machine (UTM) in preparation for tensile testing. The UTM applies an axial load to the specimen at a constant rate, gradually increasing the load until failure occurs. During the test, load-displacement data is collected continuously to generate stress-strain curves, which depict the material's response to applied forces. Key parameters such as ultimate tensile strength, yield strength, and modulus of elasticity are determined from the stress-strain curves, providing insights into the mechanical behavior of PLA material under tensile loading conditions.



#### 4.5. Analysis of Results

The tensile test results are meticulously analyzed to evaluate the mechanical properties of PLA material. Stress-strain curves are examined to identify key parameters such as yield point, ultimate tensile strength, and modulus of elasticity.

Even if a CAD tool added a feature to automatically generate an infill for a solid part, the computational analysis of that part with the finite element method would have additional challenges. Infill geometry makes the domain incredibly complex and strains the algorithms which drive the finite element solutions. The number of elements in a part STL file that includes infill geometry increases the number of elements by one to two orders of magnitude depending on the complexity of such geometry (as observed from prior SolidWorks experimentation and experience. [4])

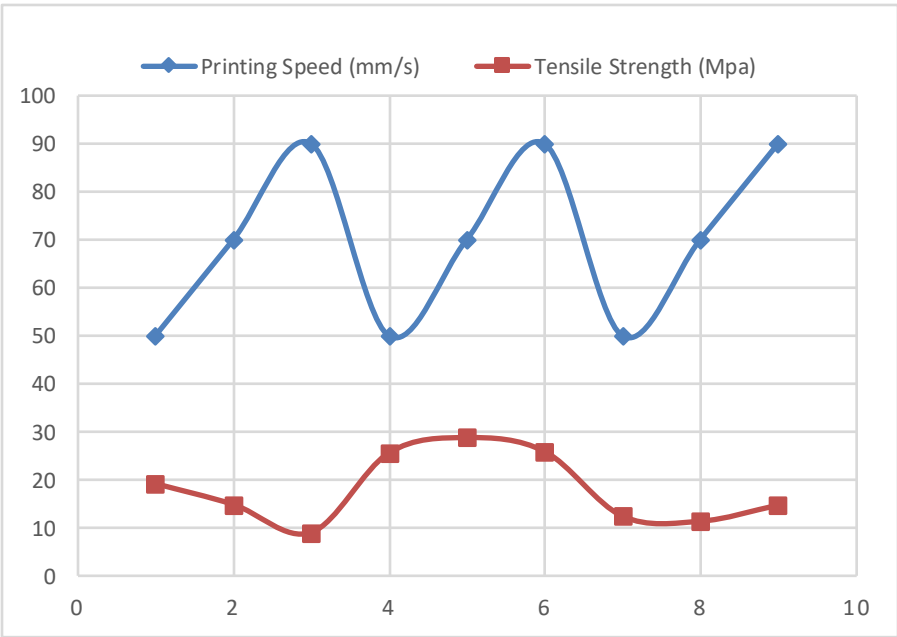
Experimental data is compared with theoretical values and literature references to validate the accuracy of test results. Any discrepancies or deviations from expected behavior are investigated and discussed in detail. The significance of the obtained

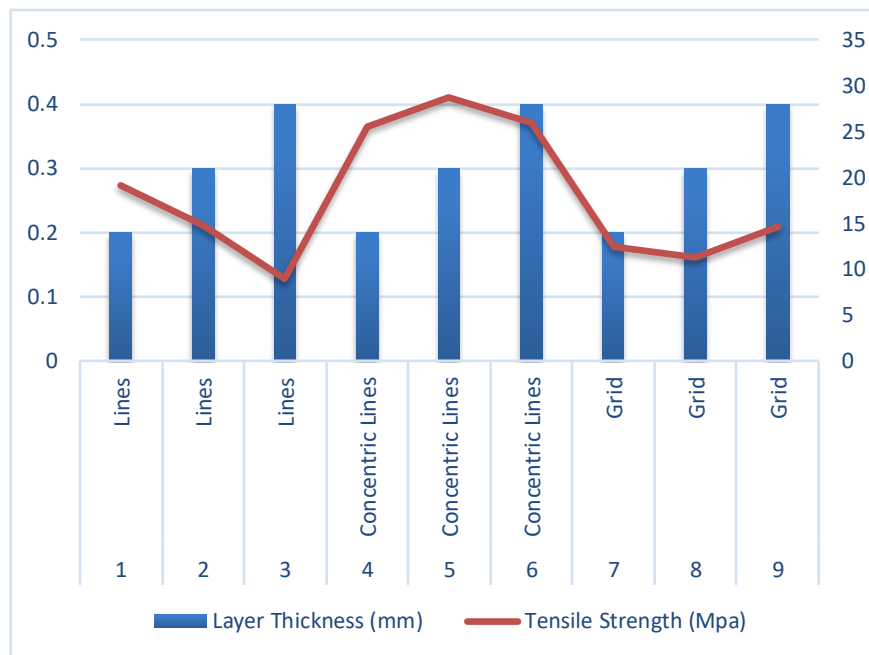
mechanical properties in the context of 3D printing applications is thoroughly explored, including implications for part design, material selection, and process optimization.

**TABLE 2.**  
**Result of experimental run for tensile testing PLA specimens**

Run	Infill Pattern	Layer Thickness (mm)	Printing Speed (mm/s)	Tensile Strength (Mpa)
1	Lines	0.2	50	19.1985
2	Lines	0.3	70	14.8633
3	Lines	0.4	90	8.99313
4	Concentric Lines	0.2	50	25.5941
5	Concentric Lines	0.3	70	28.7929
6	Concentric Lines	0.4	90	25.9117
7	Grid	0.2	50	12.4190
8	Grid	0.3	70	11.3475
9	Grid	0.4	90	14.6964

**Figure 9. Effect of Printing Speed on Tensile Strength**



**Figure 10. Effect of Layer Thickness on Tensile Strength**

#### 4.6. Validation and Quality Control

To validate the performance of the fabricated 3D printer, test prints of benchmark objects are produced using PLA material. Benchmark objects include geometric shapes, calibration cubes, and standardized test specimens designed to evaluate dimensional accuracy, surface finish, and structural integrity. Printed parts are inspected visually and dimensionally using precision measurement tools to assess print quality and adherence to design specifications. Calibration of printer settings, including extrusion rate, layer height, and print speed, is performed based on validation results to ensure consistent and reliable performance for subsequent testing and production activities.

## V. FUTURE RESEARCH DIRECTIONS

As the field of additive manufacturing continues to evolve, there are several promising avenues for future research that can further advance the fabrication of 3D printers and the testing of materials. One potential area of exploration is the development of novel 3D printer designs and fabrication techniques that enhance printing speed, resolution, and reliability while reducing manufacturing costs. This could involve the integration of advanced materials, such as carbon fiber-reinforced polymers or metal composites, to improve the structural integrity and performance of printed parts. Additionally, research into alternative printing methods, such as multi-material printing or bioprinting, holds promise for expanding the capabilities of additive manufacturing in various industries, including healthcare and biotechnology.

Furthermore, advancements in material science and engineering offer opportunities to explore new materials for 3D printing applications, beyond the traditional thermoplastics and metals. Research into bio-based polymers, sustainable materials, and advanced nanocomposites could lead to the development of eco-friendly and high-performance materials suitable for additive manufacturing. Moreover, investigations into material characterization techniques and predictive modeling of material properties can provide valuable insights into the behavior of printed parts under different loading conditions, enabling more accurate design and optimization of 3D printed components.

In addition to advancements in printer design and materials, future research efforts can focus on improving testing methodologies for evaluating the mechanical properties of 3D printed materials. This includes the development of standardized testing protocols and validation methods for assessing the accuracy and reliability of mechanical tests conducted on 3D printed specimens. Furthermore, research into non-destructive testing techniques, such as acoustic emission testing or digital image correlation, can offer alternative approaches for characterizing the mechanical behavior of printed parts without compromising their integrity.

Overall, future research in the field of 3D printer fabrication and material testing is poised to drive innovation and enable the widespread adoption of additive manufacturing technologies across industries. By addressing key challenges and exploring new opportunities, researchers can contribute to the continued growth and evolution of additive manufacturing, paving the way for more sustainable, efficient, and versatile manufacturing processes in the future.

## VI. CONCLUSION

In conclusion, the fabrication of 3D printers and the testing of materials, particularly Polylactic Acid (PLA) through Universal Testing Machines (UTM) for tensile testing, represent pivotal aspects of additive manufacturing. Through this review paper, we have explored the intricate process of building a 3D printer, encompassing the selection of components, assembly procedures, and calibration techniques. Additionally, we have delved into the preparation of PLA specimens and the rigorous tensile testing process using UTM to evaluate their mechanical properties. The comparison between 3D printing and Computer Numerical Control (CNC) machining, along with the detailed examination of the G-code mechanism, provided insights into the operational principles of 3D printers. Furthermore, the analysis of future research directions highlighted the potential for continued innovation and advancement in the field, including the development of novel printer designs, exploration of new materials, and improvement of testing

methodologies. Overall, this review paper serves as a comprehensive resource for researchers, engineers, and enthusiasts seeking to deepen their understanding of 3D printer fabrication and material testing, contributing to the ongoing evolution and growth of additive manufacturing technologies.

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