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# The design and development of a laboratory for three-point bending tests on 3D printed samples.

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# The design and development of a laboratory for three-point bending tests on 3D-printed samples

The aim of this lab is to enable students to conduct three-point bending tests in adherence to the ASTM D790 standard, with the goal of characterizing the flexural properties, including strength, modulus, ductility, and toughness, of 3D printed polymer specimens. The experimental process encompasses several stages. Initially, students are tasked with the creation of 3D models, followed by the utilization of the Fused Deposition Modeling (FDM) method to fabricate samples using diverse polymer materials. Subsequently, adjustments to the span-to-depth ratio and cross-head motion rate are essential to ensure precise execution of the flexural tests, conducted on a motorized force test stand. The data acquisition system records load and deflection values, which are then employed for calculating stress and strain, adhering to the ASTM D790 standard. Finally, stress-strain curves are constructed using the calculated stress and strain values for each polymer material, thereby enabling the comprehensive assessment of flexural properties across different polymer types. This new laboratory setup not only fosters hands-on learning but also provides invaluable insights into the mechanical behavior of 3D-printed polymer samples.

## Introduction

Creating a laboratory for mechanical testing of 3D printed samples is an important addition to the traditional engineering laboratory curriculum. In a rapidly evolving technological environment, 3D printing has emerged as a transformative technology, reshaping the engineering and manufacturing sectors. 3D printing has significantly impacted the manufacturing landscape due to its cost-effectiveness, recyclability of materials, and the ability to fabricate intricate geometries with high resolution [1, 2, 3, 4]. The applications of additive manufacturing are widespread, encompassing fields such as medicinal delivery, aerospace, automotive systems, and construction.

Fused Deposition Modeling (FDM) stands out as the most prevalent method of 3D printing. In FDM, a thermoplastic material, usually in the form of continuous filaments, undergoes heating and extrusion through a nozzle. This material is then deposited in successive layers, gradually forming the final object as it cools down [5, 6,7, 8]. Various parameters significantly influence the properties of 3D printed parts, including printing orientation and void fraction [5, 9]. Printing in the load-bearing direction notably enhances the mechanical strength of the produced parts. The choice of infill density is a critical factor in the 3D printing process. Opting for a low infill density facilitates rapid part printing with minimal material cost. Conversely, higher infill percentages contribute to greater strength and resistance but result in longer print times and increased material usage.

In this lab, students will utilize the Fused Deposition Modeling (FDM) technique to 3D print samples. They will create various polymer samples with different printing orientations and subsequently analyze the flexural properties of the 3D-printed samples. Students are expected to familiarize themselves with the ASTM D790 standard during the lab. Integrating this laboratory into engineering curricula offers students a unique opportunity to gain firsthand experience in an area vital to modern manufacturing.

## Materials and Method

3D printing:

Initially, students employ the Fused Deposition Modeling (FDM) technique to 3D print samples using various polymer types. PLA, PETG, and ABS were selected for this study. All 3D printed samples must adhere to the specified dimensions of 127 (length) × 12.7 (width) × 3.2 (depth) mm, in accordance with the ASTM D790 standard [10].

The samples are 3D printed with a 100% infill density and two distinct printing orientations: 0 and 90 degrees. In the 0-degree samples, the printing orientation runs along the length of the specimens, while in the 90-degree samples, it aligns with the width of the specimens as shown in Figure 1. Three samples per material type and printing orientation are created for comprehensive analysis.

Figure 1: samples with 0-degree (top) and 90-degree (bottom) printing orientations

Three-point bending test:

To comply with the ASTM D790 standard, students are required to set the span-to-depth ratio to 16:1. The span refers to the distance between two supports where the specimens will be positioned as shown in Figure 2. Given that the depth of the 3D printed samples is 3.2 mm, the support span needs to be adjusted to 51.2 mm to meet the specified ratio. Students are tasked with adjusting the cross-head motion rate to attain a straining rate of 0.01 mm/mm/min, as per the provided equation in the ASTM D790 standard:

$$R = \frac{ZL^2}{6d}$$

Here, R represents the rate of crosshead motion, $L$ is the support span, $d$ represents the depth of the samples, and $Z$ is the rate of straining of the outer fiber, set to be 0.01 mm/mm/min. The calculated rate of cross-head motion is 1.36 mm/min.

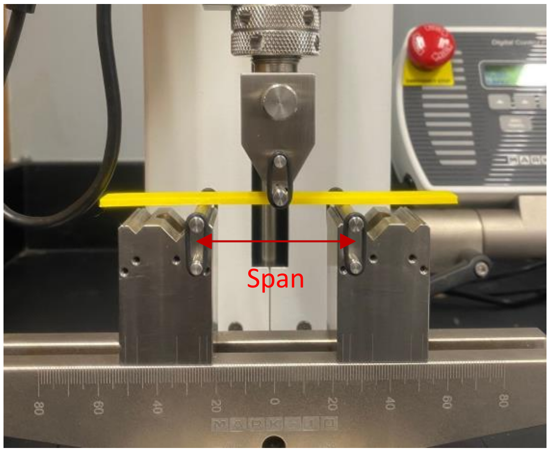


Figure 2: Three-point bending test setup

## Data Analysis

Students record load and deflection data with a data acquisition system until the sample fails. Afterward, they need to calculate stress and strain based on equations provided in the ASTM D790 standard. Stress will be calculated as

$$\sigma = 3PL/2bd^2$$

Here $\sigma$ is stress in the outer fibers at the midpoint, $P$ represents load at a given point on the load-deflection curve, $L$ is the support span, $b$ is the width of the sample, and $d$ is the depth of specimen.

Strain will be calculated as

$$\varepsilon = 6Dd/L^2$$

Here $\varepsilon$ is strain in the outer fibers at midpoint, $D$ represents maximum deflection of the center of the sample, $L$ is the support span, and $d$ is the depth of specimen.

Utilizing the stress-strain data, students perform calculations to determine the flexural properties (strength, modulus, ductility, toughness) of 3D-printed polymer samples. Flexural modulus is derived from the slope of the initial linear segment of the stress-strain curve. Flexural strength is identified at the point where stress begins to decrease on the stress-strain diagram, signifying the initial failure phase of the samples. Ductility, represented by failure strain, is determined as the strain associated with the point where stress begins to decrease. Flexural toughness is quantified as the integral of the area under the stress-strain curves up to the failure strain.

## Results and discussion

Figure 3 illustrates the typical flexural stress versus flexural strain diagrams of ABS, PLA, and PETG samples with 0 and 90-degree printing orientations. A significant difference in flexural strength and failure strain can be observed among various materials and printing orientations.

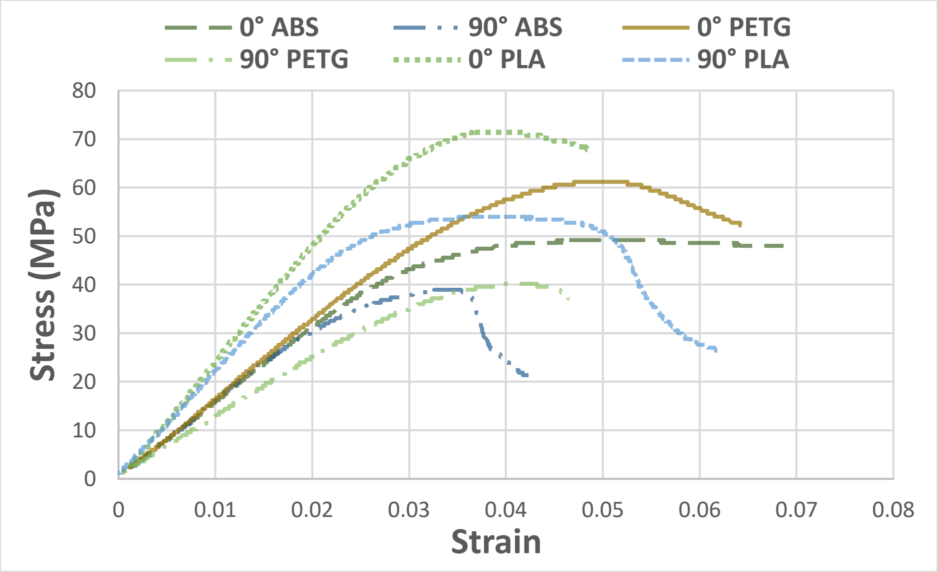
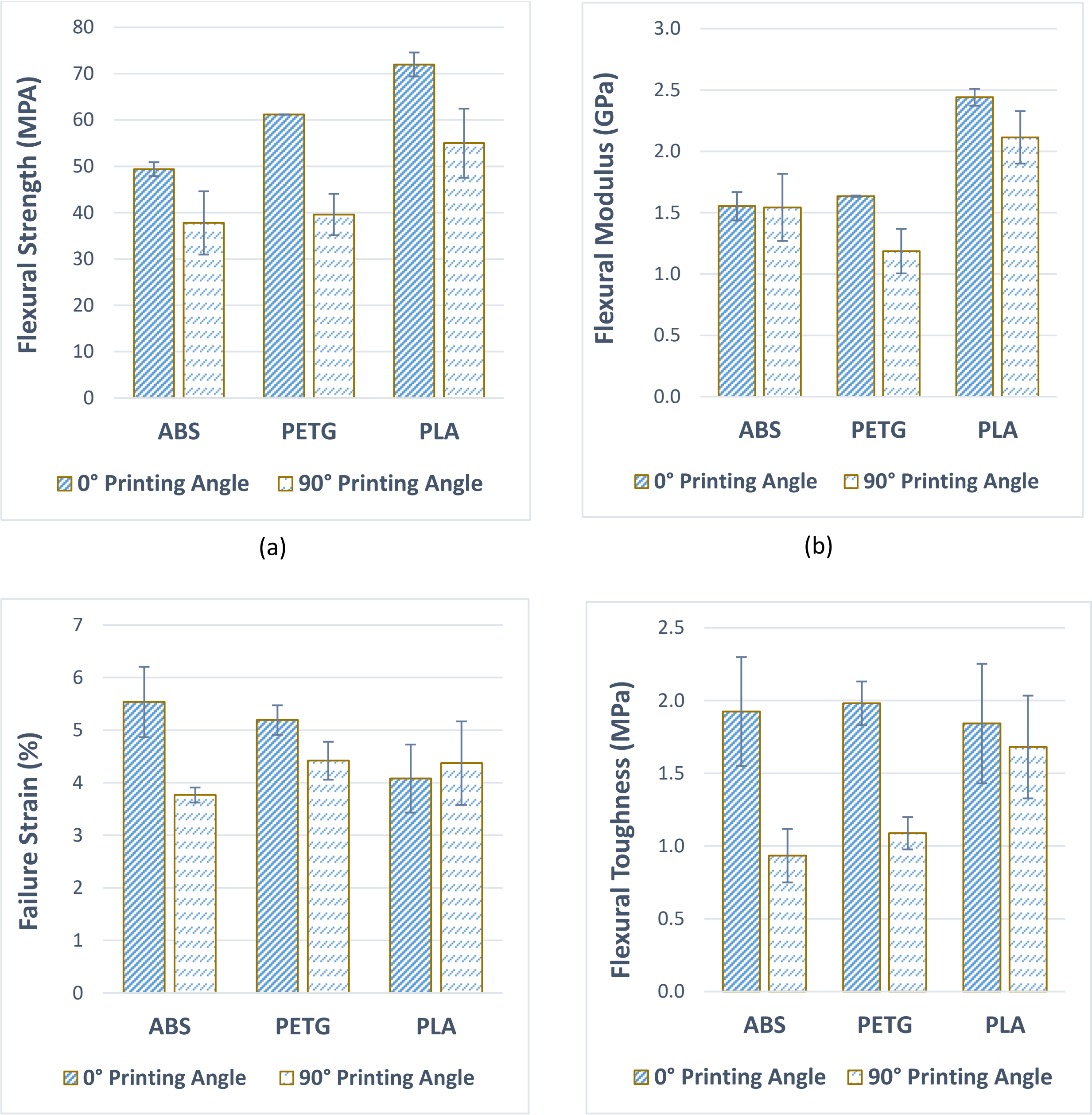


Figure 3: Typical stress-strain diagrams for different samples

The flexural properties of 3D-printed samples are presented in Figures 4(a) to 4(d). Students can engage in different discussions about the results. Some examples of these discussions are presented as follows:

In all cases, 90-degree samples exhibit lower flexural strength and flexural modulus than 0-degree samples. This is attributed to the filament deposition direction aligning with the stress developed in the 0-degree samples during the 3-point bending test, thereby enhancing the load-bearing capacity and stiffness of 0-degree samples. PLA samples show higher flexural modulus and strength compared to ABS and PETG samples in both 0-degree and 90-degree orientations. Clearly, in the case of 0-degree samples, ABS exhibits a higher failure strain compared to PETG and PLA. For 90-degree samples, PLA demonstrates greater flexural toughness than PETG and ABS, with both PLA and PETG displaying larger failure strains than ABS.



(a) (b)

(c) (d)

Figure 4: (a) flexural strength, (b) flexural modulus, (c) failure strain, and (d) flexural toughness of different 3D printed samples

## Summary of learning objectives and their fulfillment

Creation of 3D Models: Students create 3D models and use Fused Deposition Modeling (FDM) to fabricate samples, adhering to specified dimensions in accordance with ASTM D790.

Adjustments to Testing Parameters: Students adjust the span-to-depth ratio and cross-head motion rate based on ASTM D790 standards for precise flexural tests.

Data Acquisition and Analysis: Load and deflection data are recorded and analyzed as per ASTM D790 equations to calculate stress and strain.

Flexural Property Assessment: Students determine flexural properties (strength, modulus, ductility, toughness) based on stress-strain curves.

## Conclusions

The tasks to be completed by students in this laboratory include the creation of 3D printed samples, performing a 3-point bending test adhering to the ASTM D790 standard, collecting and analyzing data to determine the flexural properties of 3D printed specimens with different materials and printing orientations, and drawing conclusions based on the results. This laboratory serves as a bridge between theoretical concepts and real-world applications, equipping future engineers with the skills and knowledge required to meet the challenges of advanced and rapid manufacturing. It not only deepens their understanding of material behavior and structural analysis but also fosters problem-solving skills essential for engineering careers.

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