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# Design and Development of a Mini Tensile Test Machine to Enhance Teaching and Learning in Strength of Materials Laboratory

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## Abstract
This study presents the design and development of a Mini Tensile Test Machine (MiTTM) to enhance teaching and learning effectiveness in the Strength of Materials laboratory. The development was motivated by the unavailability of a functional conventional tensile testing machine, which limited students' opportunities for hands-on experimental learning. To address this issue, a low-cost and compact MiTTM utilizing a NEMA 17 stepper motor and lead screw mechanism was developed for small-scale tensile testing applications. The study involved 25 Diploma Mechanical Engineering students, and a quantitative approach was employed using pre-test and post-test questionnaires based on a five-point Likert scale. Experimental validation was performed using thin dumbbell-shaped PLA specimens. The findings revealed significant improvements in students' learning outcomes, with mean scores for understanding increasing from 2.39 to 4.62 and those for skills and confidence increasing from 2.62 to 4.57. Tensile testing results showed that the developed MiTTM successfully evaluated the mechanical behavior of PLA specimens, achieving an average maximum tensile load of 36.07 N and an average tensile stress of 18.03 N/mm². These results demonstrate that the proposed MiTTM is an effective, practical, and economical teaching aid that enhances students' conceptual understanding, practical skills, and confidence while promoting experiential learning in engineering education.

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## 1. Introduction

Laboratory-based learning plays a significant role in engineering education because it enables students to connect theoretical knowledge with practical applications. In Strength of Materials courses, tensile testing experiments are widely used to demonstrate fundamental concepts such as stress, strain, elasticity, plastic deformation, and material failure mechanisms. Hands-on laboratory activities have been shown to improve students' conceptual understanding, problem-solving abilities, and technical skills compared with purely theoretical instruction (Kolb, 2015). Furthermore, advances in engineering education emphasize experiential and active learning approaches to prepare students for Industry 4.0 environments, where practical competencies and digital integration are increasingly important (Hernandez-de-Menendez et al., 2019).

Despite their importance, the effectiveness of laboratory activities is often constrained by the availability and condition of testing equipment. Conventional tensile testing machines are expensive, occupy considerable laboratory space, require regular maintenance, and may experience operational downtime after prolonged usage. Such limitations often reduce students' opportunities for direct interaction with testing equipment, forcing instructors to rely on simulations or demonstrations, which may limit experiential learning outcomes (ASTM International, 2024; Callister & Rethwisch, 2018). In addition, higher education institutions are increasingly seeking affordable laboratory solutions that maintain educational effectiveness while minimizing operational costs (UNESCO, 2021).

To overcome these challenges, researchers have explored the development of low-cost and compact tensile testing systems for educational and small-scale laboratory applications. Hinge et al. (2021) developed a low-cost tabletop tensile testing machine equipped with an optical extensometer capable of generating reliable stress-strain data comparable to commercial systems. Their study demonstrated that locally sourced components and custom-developed software could significantly reduce manufacturing costs while maintaining acceptable accuracy.

Similarly, Puspaputra et al. (2024) designed a small-capacity tensile testing machine intended for educational demonstrations and lightweight material characterization. The researchers reported that the compact machine improved students' understanding of tensile testing procedures through hands-on experimentation and direct observation of material deformation. Their findings highlighted the importance of accessible laboratory equipment in promoting active learning.

More recently, Arı et al. (2025) developed an affordable tensile testing machine for educational and research applications. The system incorporated a load cell, linear motion mechanism, and digital measurement system to evaluate tensile strength and elongation. Experimental validation demonstrated satisfactory accuracy while substantially reducing fabrication costs compared with commercial universal testing machines. The authors concluded that the machine was suitable for both teaching and small-scale research purposes.

In recent years, additive manufacturing technologies have further encouraged the development of low-cost material testing systems. Kumar et al. (2023) developed and validated a compact tensile testing machine for evaluating polymer specimens produced using fused deposition modeling (FDM). Their results showed that the system provided reliable measurements for PLA specimens and could support educational and research activities involving additive manufacturing materials. Likewise, Khosravani and Reinicke (2020) highlighted the increasing importance of mechanical characterization methods for additively manufactured components, emphasizing the need for affordable and flexible testing systems.

The emergence of Industry 4.0 technologies has also influenced laboratory equipment development. Integration of sensors, microcontrollers, and digital data acquisition systems enables compact testing machines to provide real-time experimental measurements while improving usability and learning effectiveness (Javaid et al., 2022). These technologies support the transition toward smart laboratories and digital engineering education environments.

Overall, recent studies indicate that miniaturized tensile testing systems can provide reliable measurements while reducing equipment size, operational complexity, and overall cost. Although such systems may not be suitable for high-strength structural materials, they offer considerable advantages for educational applications involving polymers, composites, and lightweight materials. Therefore, the development of a Mini Tensile Test Machine represents a practical approach to overcoming the limitations associated with conventional testing equipment. By emphasizing simplicity, affordability, safety, and functionality, the proposed system can enhance experiential learning opportunities and improve students' understanding of material mechanics through direct laboratory participation.

## 2. Methodology

The development of the Mini Tensile Test Machine was carried out systematically based on engineering design methodology, which includes requirement analysis, conceptual design, mechanical and electrical design, fabrication, assembly, and testing.

A. Design and Concept Development

The initial stage involved a detailed study of conventional tensile testing machines to understand their working principles, structural requirements, and load transmission mechanisms. Based on this study, a simplified design concept for a Mini Tensile Test Machine was developed by using Computer-Aided Design (CAD) software, to produce a complete 3D model of the machine. The design focused on compactness, cost-effectiveness, safety, and suitability for laboratory teaching purposes. **Figure 1** shows the design of Mini Tensile Test Machine complete with the component.

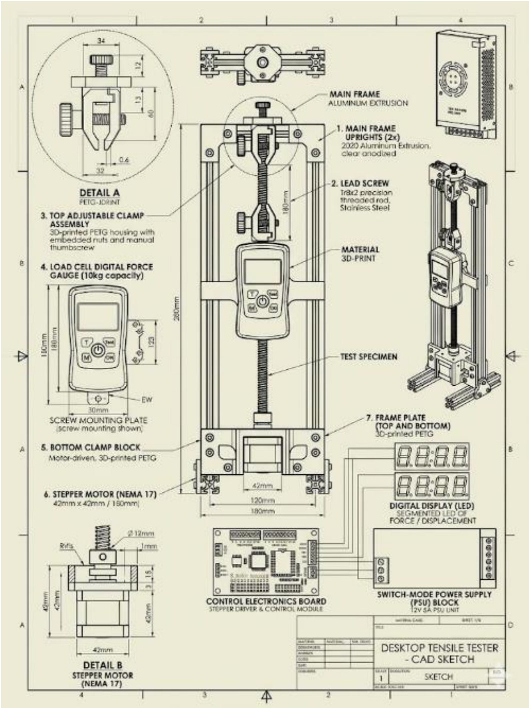


**Figure 1.** Design of mini tensile test machine

B. Material Selection and Component Procurement

After finalizing the design, the required materials and components were identified based on functional and mechanical requirements. Selection criteria included cost, durability, availability, and suitability for educational use. The main mechanical components selected included aluminium profile framing, lead screw system, bearings, shaft, and specimen clamps. For the electrical system, a NEMA 17 stepper motor, motor driver, motor controller, and power supply were chosen. All components as in **Figure 2** were then procured according to the finalized design specifications to ensure compatibility and ease of integration during assembly.

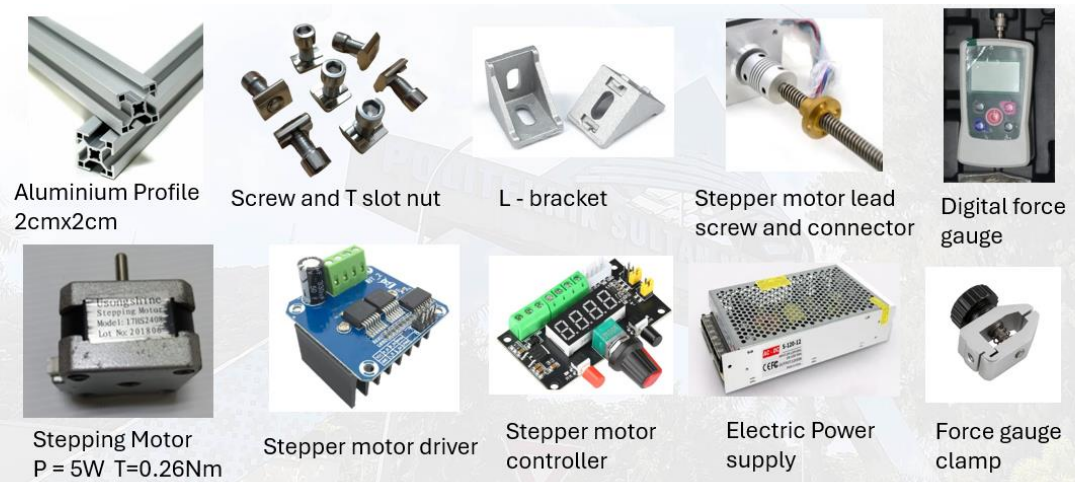


**Figure 2.** Material and component of MiTTM

C. Fabrication of Structural Components

**Figure 3** present the brackets and protective housings designed in Autodesk Fusion 360 to support the mechanical assembly and ensure proper alignment and protection of the components. These parts were then exported into STL format for 3D printing. The fabrication process was carried out using a 3D printer (Creality K2), with printing parameters set using Creality Print 6.3 software to ensure dimensional accuracy and structural strength. The fabricated components were used to support mechanical assembly and improve system integration.

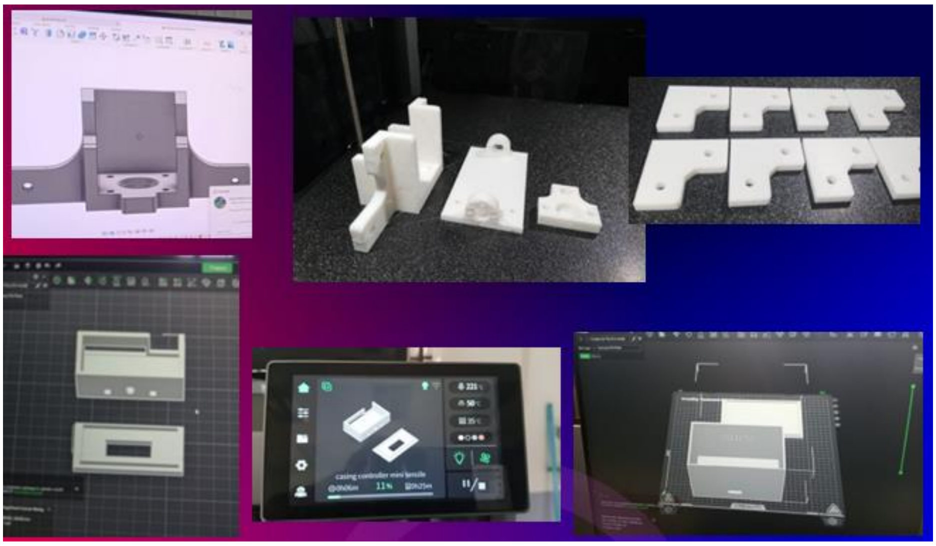

**Figure 3.** Fabrication of customize component

D. Mechanical and Electrical Assembly

The mechanical assembly involved constructing the main frame using aluminium profiles and installing the lead screw mechanism. The specimen gripping system, shaft, and bearings were carefully aligned to ensure smooth tensile motion. Subsequently, the electrical system was integrated, including the installation of the NEMA 17 stepper motor, motor driver, controller unit, and power supply system. All components were securely mounted within the designed housing to ensure safety and compactness as shown in **Figure 4**.

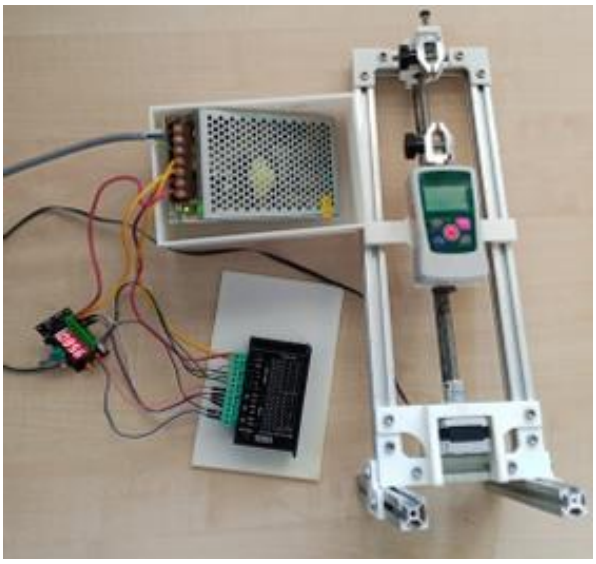

**Figure 4.** Wiring and installation of components

E. System Testing and Improvement

The Mini Tensile Test Machine was tested to evaluate its functionality, mechanical stability, and tensile loading capability. Small-scale specimens made of Polylactic Acid (PLA) were used to assess the system performance under loading conditions. Based on the testing results, several improvements and refinements were implemented to enhance system stability, alignment, and operational efficiency. As shown in **Figure 5**, the functionality testing setup demonstrates the Mini Tensile Test Machine during tensile testing of a PLA specimen, verifying the machine's ability to apply tensile loads and produce controlled specimen deformation


**Figure 5.** Functionality testing

F. Educational Implementation and Evaluation

The finalized system was implemented in the Strength of Materials laboratory as a teaching aid. Twenty-five Diploma Mechanical Engineering students participated in learning sessions using the developed system. A quantitative evaluation was conducted using pre-test and post-test questionnaires based on a five-point Likert scale to assess students' understanding, skills, and confidence before and after using the innovation. The collected data were analyzed to determine the effectiveness of the Mini Tensile Test Machine in improving teaching and learning outcomes. **Figure 6** shows the tensile testing laboratory session, where students actively performed tensile tests using the developed Mini Tensile Test Machine. The figure illustrates the hands-on learning environment and demonstrates the practical application of the innovation in enhancing students' understanding of material behavior and tensile testing procedures.

**Figure 6.** Tensile test laboratory session using the Mini Tensile Test Machine.

G. Material Tensile Test

The primary purpose of a tensile test is to determine material properties such as yield strength, ultimate tensile strength, Young's modulus, and elongation. In this study, small-scale Polylactic Acid (PLA) specimens were tested using the developed Mini Tensile Test Machine (MiTTM). The specimens were fabricated by 3D printing and designed in a thin dumbbell shape to concentrate stress within the gauge section and promote fracture at the center, minimizing failure at the grips. Specimen dimensions were measured to determine the cross-sectional area and calculate stress values. As shown in Figure 7, the thin dumbbell-shaped PLA specimen provided a suitable geometry for reliable tensile testing and observation of material deformation and fracture behavior.

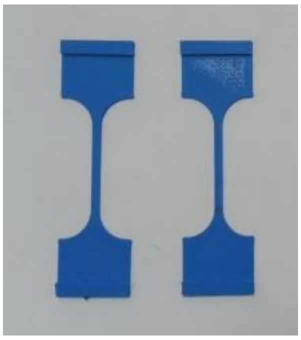

**Figure 7.** Thin dumbbell-shaped PLA specimen used for tensile testing in the MiTTM

## 3. Result & Discussion

A. Development and Utilization of the Mini Tensile Test Machine (MiTTM)

A Mini Tensile Test Machine (MiTTM) was successfully developed to provide a low cost and portable solution for teaching and learning activities in the Strength of Materials laboratory as shown in **Figure 8**. The system was designed using a NEMA 17 stepper motor, a lead screw mechanism, and a load cell for force measurement. Thin dumbbell-shaped PLA specimens were used to evaluate the performance of the machine under tensile loading. The developed MiTTM enabled students to conduct hands-on tensile testing experiments and observe material deformation and fracture behavior in real time. Experimental results demonstrated that the machine operated effectively and enhanced student's understanding of stress, strain, and the mechanical properties of materials. Its compact design, ease of operation, and affordability make MiTTM a suitable teaching aid for educational laboratories and TVET institutions.

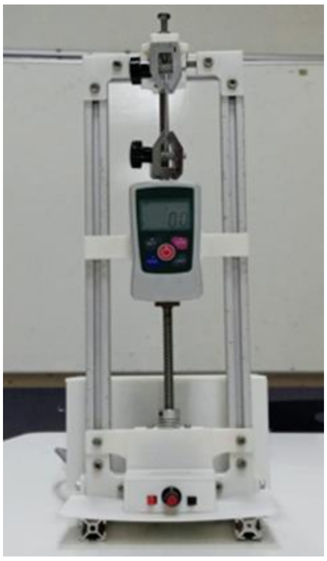

**Figure 8.** Mini tensile test machine (MiTTM)

The statistical analysis presented in **Table 1** shows a significant improvement between the pre-test and post-test scores following the implementation of the Mini Tensile Test Machine (MiTTM). The mean score for students' understanding increased from 2.39 (SD = 0.52) in the pre-test to 4.62 (SD = 0.48) in the post-test. Similarly, the mean score for students' skills and confidence improved from 2.62 (SD = 0.48) to 4.57 (SD = 0.50) after using the MiTTM.

**Table 1.** Analysis of MiTTM effectiveness

| Construct | Pre-test Mean (M) | Standard Deviation (SD) | Post-test Mean (M) | Standard Deviation (SD) |
|---|---|---|---|---|
| Understanding | 2.39 | 0.52 | 4.62 | 0.48 |
| Skills and Confidence | 2.62 | 0.48 | 4.57 | 0.50 |

These findings indicate that the use of MiTTM positively influenced student's understanding, practical skills, and confidence in conducting tensile testing experiments. The substantial increase in post-test scores demonstrates that MiTTM effectively enhanced the teaching and learning process in the Strength of Materials laboratory by providing students with hands-on experience and greater engagement in experimental activities.

B. Tensile Testing of PLA Specimens

The tensile test was conducted on three thin dumbbell-shaped PLA specimens with an average gauge cross-sectional area of approximately 2 mm² using the developed Mini Tensile Test Machine (MiTTM). The cross-sectional area was used in determining the tensile stress values from the measured tensile loads. **Figure 9** shows the fractured PLA specimens after testing. All specimens exhibited fracture within the gauge section, indicating that the dumbbell-shaped geometry effectively concentrated stress in the central region and minimized failure near the gripping areas. Variations in fracture location and elongation behavior among the specimens were observed, reflecting differences in tensile performance. The fractured specimens provide visual evidence of material deformation and failure characteristics, demonstrating the capability of the MiTTM to perform tensile testing and evaluate the mechanical behavior of PLA materials.

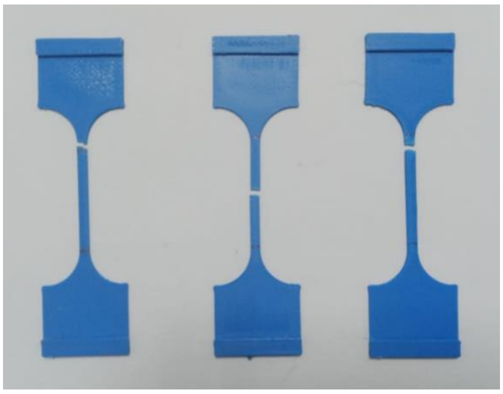

**Figure 9.** Tested PLA specimens

The results indicate variations in the maximum tensile load and corresponding maximum tensile stress among the specimens as shown in **Table 2**. Specimen 3 exhibited the highest tensile performance, recording a maximum tensile load of 40.9 N and a maximum tensile stress of 20.45 N/mm². Specimen 2 showed the lowest values, with a maximum load of 28.3 N and a tensile stress of 14.15 N/mm². The average maximum tensile load and stress obtained from the three specimens were 36.07 N and 18.03 N/mm², respectively. These results demonstrate that the developed MiTTM was capable of measuring tensile behavior and identifying differences in the mechanical response of PLA specimens under tensile loading.

**Table 2.** Tensile test results of PLA specimens

| Specimen | Max Tensile Load (Newton) | Max Tensile Stress ($N/mm^2$) |
|---|---|---|
| 1 | 39.0 | 19.50 |
| 2 | 28.3 | 14.15 |
| 3 | 40.9 | 20.45 |
| Average | 36.07 | 18.03 |

The results show that specimen 3 achieved the highest tensile strength, while specimen 2 exhibited the lowest tensile resistance. The variation in the measured values may be attributed to differences in specimen fabrication, dimensional accuracy, or internal defects commonly associated with 3D-printed PLA materials. Overall, the MiTTM successfully performed tensile testing and provided consistent measurements for evaluating the mechanical properties of the specimens.

## 4. Conclusion

The implementation of the Mini Tensile Test Machine (MiTTM) in teaching and learning activities has demonstrated a positive impact on students' understanding and engagement in Strength of Materials laboratory sessions. Prior to the introduction of MiTTM, students learned tensile testing concepts primarily through theoretical explanations, specimen observation, and demonstration videos because the existing tensile testing machine was not operational. This situation limited students' understanding of the actual tensile testing process and reduced their confidence in performing experiments.

Following the introduction of MiTTM, students were able to conduct hands-on laboratory activities using small-scale specimens. They were able to directly observe specimen elongation, material deformation, and fracture behavior during the testing process. This experience enhanced their understanding of stress, strain, and the mechanical properties of materials in a clearer and more effective manner.

Furthermore, the results obtained from pre-test and post-test assessments indicated a significant improvement in students' level of understanding and confidence after using MiTTM. Students also exhibited greater interest and motivation toward laboratory learning as they were actively involved in real experimental activities. These findings demonstrate that the use of innovation-based teaching aids can enhance the effectiveness of teaching and learning in the TVET field.

In addition, MiTTM proved to be a low-cost alternative to conventional industrial tensile testing machines, which are expensive and require substantial maintenance costs. Its simple design, portability, and ease of operation make it highly suitable for educational laboratories and TVET institutions.

Overall, the development of the Mini Tensile Test Machine (MiTTM) has successfully enhanced the effectiveness of the teaching and learning process for the Strength of Materials course, particularly in tensile testing experiments. The use of MiTTM enables students to perform hands-on laboratory activities and develop a better understanding of stress, strain, and material deformation behavior.

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