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# MINI EQUIPMENT FOR TENSILE TESTING OF SAMPLES MANUFACTURED BY 3D PRINTING FROM POLYMER MATERIALS

BY

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**Abstract.** For small-sized specimens and materials with lower mechanical properties, it may be necessary to use mini-machines for tensile testing of such materials. This situation may occur, for example, with specimens manufactured by 3D printing from polymeric materials. To solve this problem, a manually-operated mini-equipment was designed and built for tensile testing of small-sized specimens. Preliminary tests performed on this mini-equipment have proven its usability.

**Keywords:** tensile testing, small-sized specimens, 3D printing, mini-equipment, manual operation, preliminary testing.

## 1. Introduction

Polymeric materials are composed of natural or synthetic macromolecules and are characterized by diverse properties, such as flexibility,

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chemical resistance, and ease of processing (Callister and Rethwisch, 2018). Due to these characteristics, they are widely used in industrial fields such as automotive, body and interior components, packaging, films (Chanda and Roy, 2017), medicine, prostheses and medical devices (Ehrenstein, 2001), civil and industrial construction, insulations and pipes (Strong, 2006), etc.

These materials are classified into three main categories: *thermoplastics*, which can be remelted and reused (Mark, 2009), *elastomers*, with high elasticity (Utracki, 2002), and *thermosets*, which irreversibly harden upon heating (Ehrenstein, 2001).

Manufacturing processes for polymeric parts include traditional methods, such as casting, extrusion, and injection molding (Strong, 2006), as well as modern technologies, such as 3D printing (Gibson *et al*., 2015). The latter involves layer-by-layer fabrication of the part based on a digital model, using technologies such as FDM (*Fused Deposition Modeling*), SLA (*Stereolithography*), SLS (*Selective Laser Sintering*), or DLP (*Digital Light Processing*) (Ligon *et al*., 2017), each having specific advantages depending on the complexity and requirements of the final part.

The FDM (Fused Deposition Modeling) 3D printing process consists of melting a polymeric filament and depositing it layer by layer on a platform, followed by cooling and solidification of the material to form the desired part. This process is widely used due to its simplicity, low cost, and ability to work with various thermoplastic materials, such as ABS, PLA, or PETG (Gibson *et al*., 2015; Turner *et al*., 2014).

When designing polymeric parts, key properties must be known, such as mechanical strength, elasticity, high-temperature resistance, impact behavior, dimensional stability, and chemical resistance, as they influence the durability and functionality of the part under specific operating conditions (Callister and Rethwisch, 2018).

Tensile testing is a standardized method for mechanical characterization of materials, in which a specimen is subjected to an increasing tensile force until fracture, allowing the determination of properties such as yield strength, tensile strength, and elongation at break. This test provides essential information about the material's behavior under load and is used for polymers, metals, and composites alike (ASTM D638, 2022; ISO 527-1, 2019).

A mini-equipment for tensile testing is necessary when fracture forces are very low, below 200 kgf, because conventional testing machines, calibrated for high forces, up to 2000 kgf, cannot measure values below 10% of their maximum capacity with sufficient accuracy (Zhang *et al*., 2018). This is because, at very low loads, the relative errors of force transducers and data acquisition systems become significant, affecting result reliability (Chen *et al*., 2020). Mini-equipment is specially designed to operate in low-force ranges, e.g., below 200 kgf, offering enhanced sensitivity and accuracy, essential for the correct characterization of low-strength materials, such as certain polymers in film or thin fiber form (Wang *et al*., 2019). Thus, such equipment ensures precise and reproducible measurements under conditions where standard machines would yield unreliable results (Li *et al*., 2021).

Researchers have developed high-precision mini-equipment for tensile testing at low forces, below 200 kgf, required for testing soft materials, fibers, or thin films (Kim *et al*., 2020). These devices provide enhanced sensitivity through specialized transducers and integration with microscopy techniques, allowing accurate strain measurements at low loads (Park *et al*., 2021). Some models use piezoelectric actuators or MEMS sensors, achieving resolutions below 1 µm and errors under 0.5% (Lee *et al*., 2022). Studies confirm that such mini-equipment is indispensable for testing various biomaterials, in nanotechnology and advanced polymers, where conventional machines lack sufficient precision (Smith *et al*., 2023). Additionally, it has been demonstrated that they only provide reliable results with rigorous calibration and automated parameter control.

The research objectives focused on the design, development, and preliminary testing of a mini tensile testing device adapted for low-force testing and capable of manual operation. The structure of the study allowed the achievement of the objectives by briefly presenting the testing methodology, the proposed design solution, and the preliminary test results of the mini-equipment.

## 2. Requirements for Tensile Testing

The types of mechanical stresses that can occur in components during operation include: tension (tensile stress); compression; bending; shear; torsion; combined bending and torsion (complex stresses).

Tensile stress involves applying an axial force that elongates the component, generating tensile stresses in the cross-section (Fig. 1).

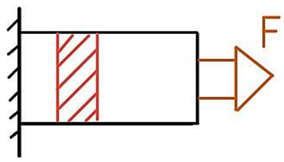



Fig. 1 – Tensile stress.

Determination of tensile strength involves subjecting a specimen with dimensions complying with specific regulations to an increasing axial force until fracture, while simultaneously recording the elongation and applied force to obtain the characteristic stress-strain curve. This process allows establishing the values of parameters such as yield strength, tensile strength, Young's modulus, and elongation at break, which define the material's ability to withstand tensile loads. The results are important for material characterization, validation of various designs, and prediction of material behavior under real operating conditions.

For determining tensile strength, the fundamental relation is used:

$$\sigma = \frac{F}{A}, \tag{1}$$

where $\sigma$ represents the normal stress (tensile strength in MPa), $F$ – the applied axial force (in Newtons), and $A$ – the initial cross-sectional area of the specimen (in $mm^2$).

This equation allows the calculation of the unit stress to which the material is subjected, and the maximum value obtained before fracture represents the tensile strength ($R_m$). In parallel, the relation for specific strain can be used:

$$\varepsilon = \frac{\Delta L}{L_0}, \tag{2}$$

where $\Delta L$ is the elongation of the specimen, and $L_0$ – the initial reference length.

Essential for plotting the characteristic curve and determining the elastic modulus $E$ is the relation:

$$E = \frac{\sigma}{\varepsilon}. \tag{3}$$

For the analysis of the 3D printing process and variable parameters, a 3D model of a specimen was developed according to recommendations found in the specialized literature (van Zyl, 2016). The specimen dimensions can be seen in Fig. 2.

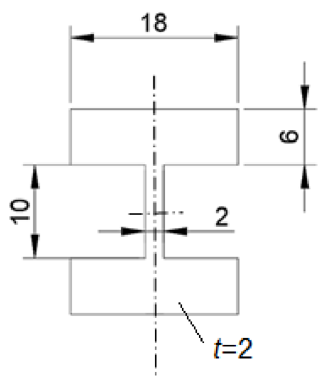



Fig. 2 – Dimensions of mini-specimens (adapted from van Zyl, 2016).

A force-elongation or stress-strain diagram highlights the behavior of a material during loading, showing the direct relationship between the applied load and the resulting elongation. The diagram illustrates both *the elastic zone*, where the material deforms reversibly according to Hooke's law, and *the plastic zone*, where permanent elongation occurs, up to the fracture point. The characteristic curve allows identification of yield limits, maximum strength, and material ductility, providing crucial information about its load-bearing capacity under real operating conditions. The graphical representation typically includes *an initial linear zone* (corresponding to elastic behavior), followed by *a nonlinear region* (plastic behavior), and *ends with the fracture point*.

A tensile testing machine must be precise, versatile, and safe. It includes:

- A load cell for force measurement;
- An actuation system with adjustable speed;
- Special grips for clamping the specimen;
- Extensometers for strain measurement.

A rigid steel frame must ensure stability, and integrated software should process data and generate stress-strain diagrams. The equipment components work together to apply controlled forces and precisely measure material response, providing reliable results according to international standards. In Fig. 3, the key components of a tensile testing equipment and their respective roles can be observed.

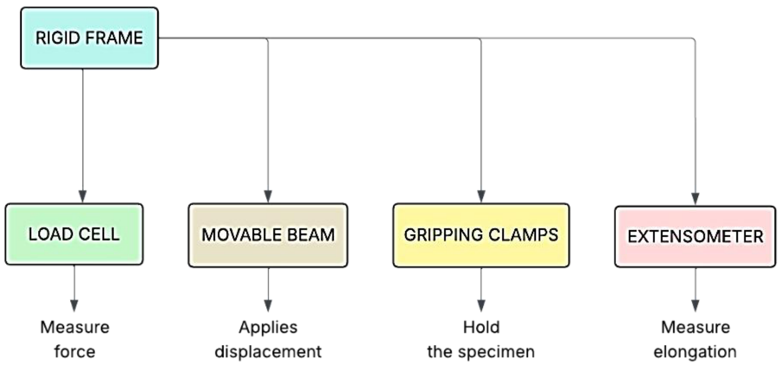



Fig. 3 – Key components of a tensile testing equipment and their roles.

## 3. Specific Aspects of Tensile Testing Mini-Specimens

Tensile testing of mini-specimens is necessary for materials with small dimensions or available in limited quantities, such as thin wires, films, microelectromechanical components (MEMS), or advanced materials with microscopic-scale structures. This approach is essential in the research of biomaterials, nanomaterials, or thin-layered materials, where local mechanical properties may differ significantly from those of the bulk material. Tests on mini-specimens are also used in the microelectronics and medical industries for characterizing miniaturized components, such as in reliability studies, where small sample sizes are dictated by specific operating conditions.

The use of mini-specimens involves specific challenges compared to standard specimens, due to their small size and increased sensitivity to external factors. Sample preparation requires precise processing methods (e.g., liquid or gas jet cutting) to avoid microscopic defects that could alter test results. Strain measurement becomes complex due to instrumental limitations–conventional extensometers are now replaced by those based on optical techniques or SEM with image analysis. The small forces involved (below 10 N) require specialized transducers and strict vibration control. Material anisotropy can have a major impact due to the scale effect, and specimen misalignment errors can become critical due to the high surface-to-volume ratio. Results require statistical corrections due to high dispersion caused by microscopic heterogeneities. Typical applications include testing thin-layered materials used in microelectronics or characterizing individual fibers in composite materials.

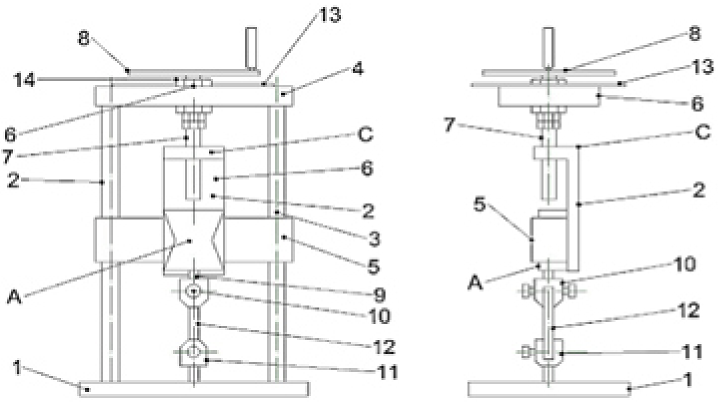
Different shapes and sizes of mini-specimens have been proposed by various researchers.

## 4. Design of a Manually Operated Mini-Equipment for Tensile Testing of Mini-Specimens

The proposed mini-equipment for manual tensile-compression testing is a compact and simple technical solution designed for testing mini-specimens of various materials. The mini-equipment does not have a complex structure, nor does it require the high costs associated with universal tensile testing machines, offering an accessible alternative for evaluating mechanical properties on a small scale.

The equipment includes a rigid frame, consisting of a base plate (1), two columns (2, 3), and a top plate (4), ensuring stability (Fig. 4). The force application system uses a screw (7), operated by a handwheel (8), which moves a collar part (6) attached to a dynamometer (A). The force is transmitted to the specimen (12) through grips (10 and 11), aligned precisely enough to avoid improper specimen loading (Țisari *et al.*, 2025).

Strain measurement (displacement of the movable grip) involves using a graduated disc (13) fixed to the screw (7); the graduated disc (13) indicates the rotation angle, correlated with specimen elongation/shortening. The force values (displayed by dynamometer A) and strain values (readable on the disc (8)) allow plotting the stress-strain diagram (Țisari *et al.*, 2025).




a b

Fig. 4 – Front view (a) and side view (b) of the mini tensile testing equipment (Țisari *et al*., 2025).

For the dynamometer, a suitable option is the AMF 500 Digital Force Gauge (Aliyiqi, China). This compact and corrosion-resistant device is designed for push-pull testing, with a measuring range of 0.1 N to 500 N, offering precise force readings directly in units of force (Newtons). The dynamometer does not require calibration, as it provides direct force measurements, eliminating the need for additional calibration steps.

Fig. 5 – Experimental Setup of the Mini-Tensile Tester.

## 5. Results of Preliminary Testing Performed on the Mini-Tensile Testing Equipment

The mini-specimens were fabricated using polylactic acid (PLA) filament, a polymeric material commonly used for 3D printing parts. The shape and dimensions of the mini-tensile specimens were adapted based on specialized literature, featuring a narrowed central section. The term "mini-specimens" was used due to their reduced size, tailored for the manually operated testing equipment.

The specimen fabrication process involved 3D printing using Fused Deposition Modeling technology. An image highlighting the shape and dimensions of a specimen is shown in Fig. 2.

The specimens were produced using a BambuLab A1 Mini 3D printer (China), a desktop 3D printing system capable of high precision and good layer deposition quality (BambuLab Technical, 2023). The 3D model of the specimens was designed using the specifications illustrated in Fig. 2.

Two internal infill density values were considered: 15% and 75%. For each infill level, two specimens were printed.

The printing process was characterized by the layered deposition of PLA material, with interlayer adhesion influenced by the specific parameters of the BambuLab A1 Mini printer (BambuLab User, 2023). No post-printing thermal or mechanical treatments were applied, with specimens tested in their as-printed condition.

**Table 1**
*Force Values Obtained Using the Mini-Tensile Testing Equipment for 3D-Printed PLA Mini-Specimens*

| Elongation $\Delta l$, mm | Force values (N) for the infill (%) of: | |
|---|---|---|
| | 15% | 75% |
| 0 | 0 | 0 |
| 0.2 | 3.40 | 79.8 |
| 0.4 | 30.50 | 145.3 |
| 0.6 | 55.3 | 151.4 |
| 0.8 | 48.4 | 140.1 |
| 1 | 33.5 | 46.3 |
| 1.2 | 19 | 35.1 |
| 1.4 | 0 | 0 |

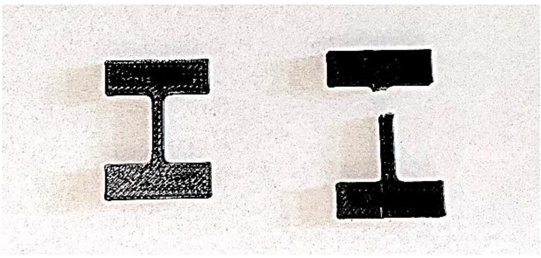


Fig. 6 – Example of a mini-specimen broken during tensile testing on the designed and fabricated equipment (mini-specimen no. 1, with 15% infill), Adapted from van Zyl *et al*. (2016).

Using the results included in Table 1, the graphic representation in Fig. 7 was created.

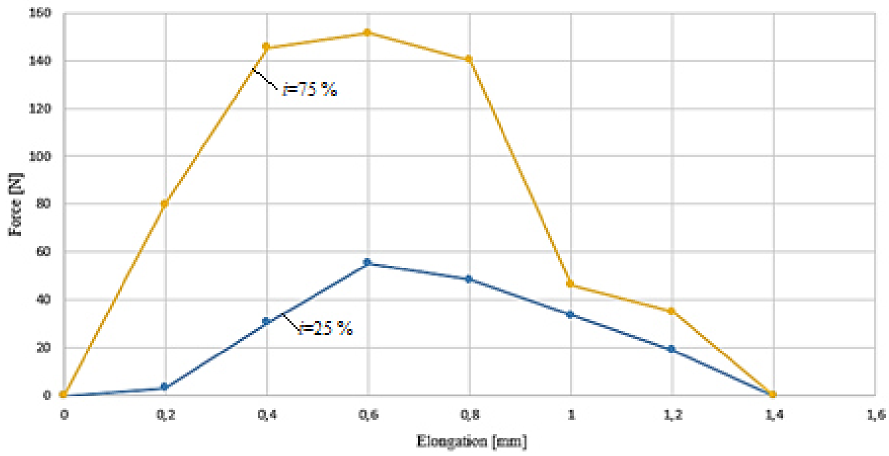



Fig. 7 – The force-elongation dependence graph for two infill values ($i$=15% and $i$=75%).

## 6. Conclusions

The research presented in this paper aimed at the design, fabrication, and preliminary testing of a mini-equipment usable for tensile testing of mini-specimens made from polylactic acid through 3D printing.

The literature review highlighted that polymer materials produced by 3D printing require precise mechanical testing, and conventional testing machines cannot accurately measure very small forces, below 200 kgf, which is why specialized mini-machines are necessary. These offer increased sensitivity and are indispensable for soft materials, fibers, or thin films, where relative errors of force transducers become significant at small loads.

The basic structure of the proposed mini-equipment included a rigid frame consisting of a base plate, two columns, and a top plate, a force application system through a manually operated screw with a handwheel, and a dynamometer for force measurement. Difficult problems, such as precise specimen alignment and strain measurement, were solved by using a graduated disc for recording the rotation angle and correlating its rotation with specimen elongation, as well as by integrating specialized gripping jaws.

Preliminary experiments consisted of testing mini-specimens with two infill values. It was assessed that the obtained results confirm the potential uses of the mini-equipment for tensile testing.

In the future, the research can be continued by implementing an electromechanical actuation of the mini-equipment and by equipping it with sensors and components that would allow digital acquisition of the force-elongation diagram. Additionally, it is intended to perform tensile tests on mini-specimens made by 3D printing from other polymer materials.

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## MINI-ECHIPAMENT PENTRU TESTAREA LA ÎNTINDERE A UNOR EPRUVETE FABRICATE PRIN TIPĂRIRE 3D DIN MATERIALE POLIMERICE

(Rezumat)

În cazul epruvetelor de mici dimensiuni și din materiale cu proprietăți mecanice mai scăzute, este posibil să fie necesară utilizarea unor mini-mașini pentru testarea la întindere a unor asemenea materiale. O astfel de situație poate să apară, de exemplu, în cazul epruvetelor fabricate prin tipărire 3D din materiale polimerice. Pentru rezolvarea unei astfel de probleme, a fost conceput și realizat un mini-echipament cu acționare manuală, pentru testarea la întindere a unor epruvete de mici dimensiuni. Teste preliminare efectuate pe acest mini-echipament au probat posibilitățile de folosire a lui.