USING THE IDEAS DIAGRAM METHOD TO DESIGN A MINI-EQUIPMENT FOR TENSILE TESTING OF 3D PRINTED SPECIMENS

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Abstract: *Some observations regarding the use of conventional tensile testing equipment have led to the need for designing and developing a mini tensile testing equipment intended for small-sized specimens made of polymeric materials fabricated by 3D printing. To identify a suitable solution for such equipment through the efficient use of technical creativity, the ideas diagram method was applied. The use of this method involved identifying several variants of the mini-equipment components, which were subsequently combined to obtain a solution considered to be the most appropriate. By applying the idea diagram method, it was possible to identify a viable solution for the tensile testing equipment, which was then materialized and subjected to preliminary experimental trials.*

Keywords: *ideas diagram method, 3D printing, tensile testing; testing mini equipment; polymeric specimens.*

1. Introduction

Performing a tensile test involves subjecting a specimen made of a certain material to a progressively increasing tensile force until fracture occurs. This test determines important mechanical properties, such as the yield strength, tensile strength, and elongation at break. A mini testing equipment is required to rapidly and economically test small-sized specimens or newly developed materials under laboratory conditions, especially when conventional tensile testing machines are not suitable for relatively low force values that cause specimen breaking. It is also considered that if the breaking force values are lower than the force range for which the standard tensile testing equipment was designed, the results obtained may not be sufficiently reliable.

3D printing is an additive manufacturing process that enables the generation of a three-dimensional object layer by layer, starting from a digital model. This technology allows for the fabrication of complex geometrical shapes that would be impossible or very costly to produce using traditional methods. It is widely used in rapid prototyping, in the manufacturing of components for industrial or domestic applications, as well as in medical and artistic fields.

3D printing belongs to the broader group of *additive manufacturing processes*. These are the opposite of subtractive processes, in which material is removed from a solid workpiece. The basic principle of additive manufacturing is the generation of objects through the successive deposition of material layers. The most widespread 3D printing processes are Fused

Deposition Modeling (FDM) and Stereolithography (SLA). FDM is widely known for its low cost, while SLA is valued for its high precision and superior surface finish of the parts produced. The process is based on melting a solid filament made of a thermoplastic material and extruding it through a heated nozzle. The nozzle deposits the molten material layer by layer, following a numerically controlled trajectory, gradually generating the three-dimensional object. The parts can be made from thermoplastic materials such as ABS (acrylonitrile butadiene styrene), PLA (polylactic acid), or PETG (polyethylene terephthalate glycol). In addition, special filaments reinforced with carbon fibers, wood, or flexible metallic materials are also available.

Polymeric materials are substances composed of long macromolecules called polymers, formed by the repetition of basic structural units known as *monomers*. These materials, such as plastics or rubber, can be either synthetic or natural and are characterized by various properties, such as flexibility and high corrosion resistance. The tensile strength of polymeric materials is generally much lower than that of metals. For example, while ordinary steel can have a tensile strength of several hundred MPa, most common plastics exhibit strengths between 10 and 100 MPa. However, some engineering polymers or fiber-reinforced polymer composites can achieve strengths comparable to those of certain non-ferrous metallic materials. A synthesis of the results shows that the mechanical properties of polymeric materials tested in tension vary greatly depending on their composition and structure.

The research conducted by Young and Lovell emphasizes how factors such as molecular chain length and degree of branching directly influence the tensile strength and elongation at break [Young, 2011]. Currently, research has focused on polymer composites, where the incorporation of fibers (glass or carbon) can significantly enhance tensile strength, reaching values that may exceed 500 MPa, as documented in reviews on advanced materials.

One of the methods for stimulating creativity that can be applied in constructive and technological design activities is the ideas diagram method. In principle, the application of the ideas diagram method involves the gradual development of a graphical representation that considers the different variants of the components of the process or equipment to be designed. By combining the component variants, it is possible to identify innovative solutions for the process or equipment that will later be designed in detail.

The main objective of the research was to design a mini tensile testing device specialized for small polymeric specimens fabricated by 3D printing. As previously mentioned, this approach was necessary because standard laboratory equipment, which is designed for much higher forces, cannot provide accurate measurements in the low-force range below 2000 N, specific to these small specimens. Therefore, the goal was to develop an accessible device capable of ensuring reliability in the mechanical characterization of materials used for small-scale specimens.

Following the review of the specialized literature, it was found that tensile tests applied to polymeric materials obtained by 3D printing are commonly reported according to the international standards ASTM D638 and ISO 527, which define both the geometry of the specimens and the testing and calculation conditions for mechanical properties [ASTM, 2014; ISO, 2019].

Recent research shows that technological parameters of the fused deposition modeling process, such as layer orientation, infill percentage, deposition speed, and temperature, directly influence the tensile strength and elastic modulus of the manufactured specimens [Appalsamy,2024; AbouelNour,2024]. The literature describes various solutions for miniaturized or low-cost devices, created by integrating simple actuators and load cells coupled with microcontrollers, demonstrating that it is possible to develop small equipment for testing 3D-printed specimens [Lim,2013; Arrizabalaga,2017; Hinge,2021; Wiranata, 2024]. Furthermore, technical challenges related to clamping miniaturized specimens, sensor calibration, and measurement accuracy at low forces are mentioned, which justifies the development of innovative design solutions [Lim,2013; Wiranata,2024].

Additionally, numerous methodological sources emphasize the positive role of using an ideas diagram in the process of designing educational and laboratory equipment, as it facilitates the identification of subsystems, the structuring of requirements, and the comparison of design alternatives. Therefore, the literature confirms both the importance of adhering to international standards and the technical feasibility of developing a mini tensile testing equipment. The ideas diagram method proves useful for organizing and accelerating the conceptual design process [InteractionDesign,2025].

Through its structure, the paper achieved this objective by applying conceptual design methods, especially the ideas diagram method, to explore technical solutions adapted to specific requirements. The systematic analysis of components led to the selection of a variant considered suitable, which ensures sufficient accuracy for forces applied to the small-sized specimen, while maintaining constructive simplicity and low cost. Validation through the functional description of the final solution showed that the designed equipment effectively meets the need for precise testing in the domain of small forces, where results obtained using conventional equipment are less reliable.

2. Specific working conditions for tensile testing

A tensile test typically involves aligning and clamping a standardized specimen in the grips of a testing machine and applying a progressively increasing tensile force until fracture. During this process, the machine simultaneously records the applied force and the elongation of the sample, generating a force-elongation or stress-strain diagram. This data allows for the determination of key mechanical properties of interest, such as the yield strength, ultimate tensile strength, and elastic modulus.

Tensile testing equipment primarily consists of a rigid frame, a force generation source (such as a hydraulic actuator or a servo-motor), a load cell for measuring the force, and a subsystem for aligning and clamping the specimen. Furthermore, a data acquisition subsystem records and processes the information, and an extensometer accurately measures the elongation of the sample.

The resulting stress-strain curve can be used to calculate the elastic modulus (Young's modulus), which characterizes the material's stiffness.

The specimen must have a standardized shape and dimensions, usually featuring a narrower calibrated section and wider ends for gripping. Whenever possible, the material of the specimen should be homogeneous and free from internal or surface defects that could affect the test results. The geometry and dimensions of the specimen must, in principle, comply with specific standards, such as those included in SR EN ISO 527-2 for plastics.

3. Idea diagram method

Professor Vitalie Belous, from the former Polytechnic Institute of Iaşi (now the "Gheorghe Asachi" Technical University of Iaşi), was notable for his significant contributions to defining and applying the ideas diagram method in the field of engineering [Belous, 1986; Belous, 1990; Belous, 1992]. His works popularized this method as an effective tool for organizing creative thinking and the design process.

The ideas diagram method involves the visual organization of thoughts under a central idea, from which thematically related secondary concepts branch out. This hierarchical structure stimulates associative thinking and provides an overview of a subject. The method is an effective tool for applying brainstorming, systematizing knowledge, and solving a wide range of problems. The ideas diagram method is part of the broader group of tree-type methods. These techniques aim at the rapid generation and visual organization of a large number of ideas without initial constraints. It falls under the category of visual thinking methods, alongside other tools such as the Ishikawa diagram or SCAMPER.

In principle, applying a tree-type method involves considering four essential steps. First, the central idea or main problem is chosen and noted, placing it in the center of a sheet. Then, secondary ideas or key categories that branch out from the central idea are identified, forming the first levels of branches. Next, each branch is expanded with detailed sub-ideas, using keywords, images, or symbols to stimulate free association. Finally, the resulting structure is analyzed, connections between concepts are identified, and the organization is refined to clarify hierarchical relationships or themes.

Research has consistently demonstrated that applying a tree-type method (such as the ideas diagram method or mind mapping) significantly improves information retention and creative thinking. In one study, participants who used mind mapping improved their ability to recall information by up to 10% more than those using traditional note-taking methods [Farrand, 2002]. Furthermore, a comprehensive analysis of its scientific validity concluded that the technique is a superior tool for idea generation (as happens in the brainstorming method), leading to a higher number and greater creativity of ideas compared to simple listing methods [Davies, 2011; Budd, 2004]. Its application in education has been associated with a deeper understanding of complex materials and better knowledge organization in technical fields.

4. Applying the ideas diagram method to the design of a mini tensile testing equipment

The main component subassemblies of a mini tensile testing equipment are: the specimen alignment and clamping subsystem, the motion guidance subsystem, the motion transformation mechanism, the actuation subsystem, the force measurement subsystem, the displacement measurement subsystem, and the base frame.

Within a mini tensile testing equipment, the structure is organized into functional subassemblies identified by alphanumeric codes. The central core of the entire structure is the Mini Tensile Testing Equipment for 3D Specimens.

The main components and their variants (Figure 1) are as follows:

A – Specimen Clamping and Alignment Subsystem, responsible for firmly gripping the ends of the specimen. This can be defined by considering the following variants:

- A1 – Mechanical clamps with tightening screws;
- A2 – Pins or needles that pass through holes in the ends of the specimen;
- A3 – Universal clamping subsystem, similar to those on standard testing machines;
- A4 – Chuck, similar to a lathe chuck;
- A5 – Vice-type subsystem;

B – Motion Guidance Subsystem, which ensures the rectilinear movement of the mobile part. The options for this are:

- B1 – "Dovetail" linear guides;
- B2 – Cylindrical guides with a cylindrical rod and linear bearings;

C – Motion Transformation Mechanism, which converts rotary motion into linear motion. This can be:

- C1 – Pinion-rack mechanism;
- C2 – Lead screw-nut mechanism;
- C3 – Ball screw-nut mechanism, for high precision and efficiency;
- C4 – Cam-follower mechanism.

D – Actuation Subsystem; this defines the provider of energy for the movement. It can take one of the following forms:

- D1 – Manual actuation with a hand crank;
- D2 – Actuation with a Direct Current (DC) electric motor;
- D3 – Actuation with a stepper motor, ideal for precise control;
- D4 – Actuation with a servomotor;

E – Force Measurement Subsystem, which detects and records the variation of the force applied to the specimen. The variants considered are:

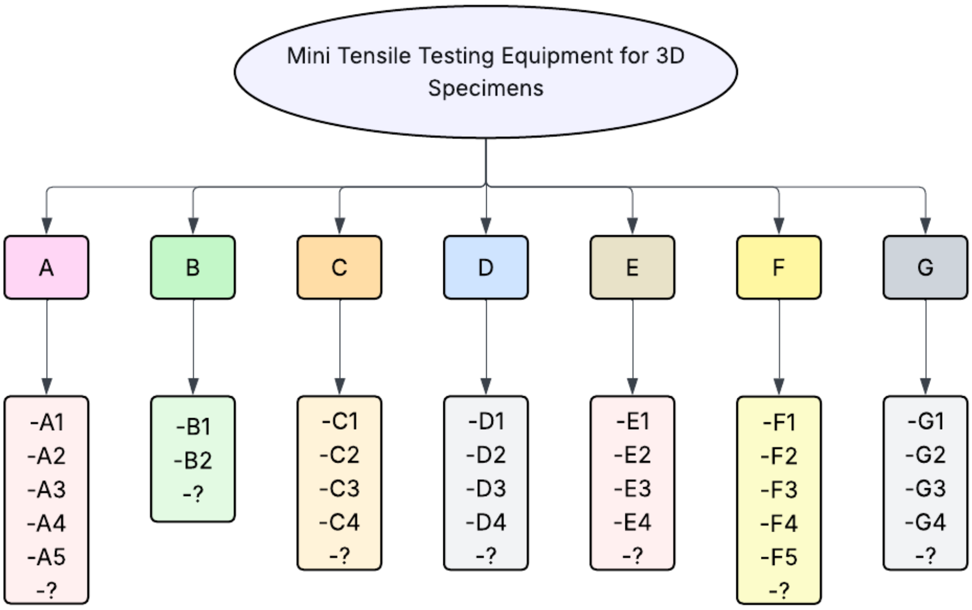

Figure 1: *Ideas diagram for the structure of the mini tensile testing equipment for 3D printed specimens*.

- E1 – Mechanical dial dynamometer;
- E2 – Digital dynamometer.
- E3 – Force sensor (load cell) with a data acquisition system;
- E4 – Subsystem with a spring and displacement indicator;

F – Displacement Measurement Subsystem, which measures the elongation of the specimen. This can be:

- F1 – Mechanical subsystem similar to that of a caliper;
- F2 – Dial indicator;
- F3 – Laser distance measuring device;
- F4 – Linear Variable Differential Transformer (LVDT);
- F5 – Rotary encoder mounted on the motor or screw shaft;

G – Frame or Base Part, which provides rigid support for the entire assembly. The options for the base piece are:

- G1 – Rigid horizontal plate made of aluminum, steel, or MDF;
- G2 – Mounting components on the worktable of a drilling machine;
- G3 – Mounting components on a universal lathe;
- G4 – Frame made of aluminum alloy profiles.

The systematic coding of components and their variants allows for a clear methodological approach in the conceptual design phase of the mini equipment.

In accordance with the recommendations of Professor Belous, at the bottom of each column in the idea diagram and respectively at the far right end of the line corresponding to the various subsystems, a placeholder containing a question mark was placed. This question mark emphasizes that the diagram is valid at a specific date, with the possibility of being supplemented later [Belous, 1986].

5. The solution resulting from the combination of specific variants of the components for the mini tensile testing equipment

The selected technical solution, coded by the combination A1B1C2D2E2F2G1, materializes a mini tensile testing equipment with electric actuation, which translates the essential design criteria into practice: technological accessibility, low cost, and basic functionality. The equipment is based on a rigid frame using an aluminum alloy plate (G1) that ensures structural stability. Integrated onto this is a guidance subsystem comprising bushings and rods (B1), which direct the rectilinear movement of the clamp-carrying sled. The electric actuation (D2) ensures simple and reliable operation, eliminating the need for complex components and substantially reducing costs. The lead screw-nut mechanism (C2) efficiently transforms the rotary motion obtained with the help of a DC electric motor into controlled linear displacement.

The force measurement subsystem uses a digital dynamometer (E2) mounted in the line of force application, providing clear and sufficiently accurate readings for educational applications. The clamping of the 3D-printed specimens is achieved through simple mechanical clamps (A1), a robust and easily manufactured solution. For measuring elongation, a dial indicator (F2) is positioned to allow for the recording of the sled's displacement. This configuration ensures optimal maneuverability and simple maintenance, adhering to the criterion of ease of use.

Although designed for simplicity, the equipment (Fig. 2) maintains a modular architecture, allowing for future upgrades, such as replacing the dynamometer with a load cell or integrating an automated actuation system. Thus, the final solution represents a balance between performance, cost-effectiveness, and versatility, constituting a reliable testing platform for the preliminary characterization of the tensile strength of polymer materials embedded in parts fabricated by 3D printing.

Currently, a version of the mini equipment with manual actuation has been completed, and the version with actuation via a DC electric motor is under construction.

6. Conclusions

The main objective of the research was the design of a mini tensile testing equipment, specialized for small-sized polymer specimens manufactured by 3D printing. This endeavor was necessary because standard laboratory equipment, designed for much higher forces, does not provide precise and reliable measurements in the domain of very small forces, below 2000 N, specific to small-sized specimens. The goal was to create a viable alternative that would balance accuracy, low cost, and ease of use, addressing a practical need in laboratories with limited resources.

The result of the research was the design of a manual mini tensile testing equipment, specialized for small-sized polymer specimens

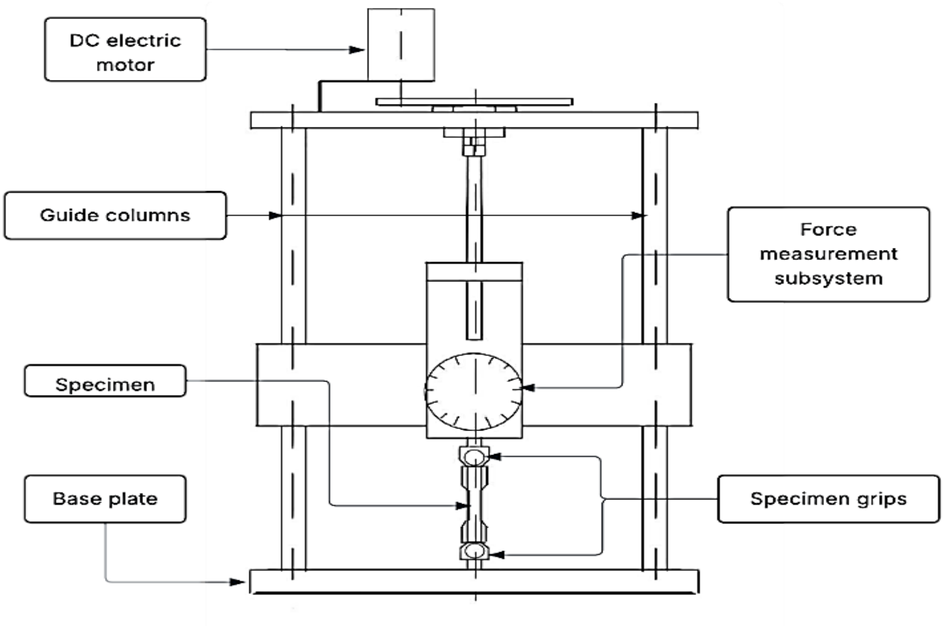

Figure 2: *Simplified representation of the mini tensile testing equipment for small-sized polymer specimens manufactured by 3D printing.*

manufactured by 3D printing. This solution solved the specific problem of testing at very low forces (below 1000 N), for which standard equipment, designed for high forces, does not provide precise and reliable results. By applying the idea diagram method, the technical solution defined by the component combination A1B1C2D2E2F2G1 was reached, which ensures a balance between functionality, low cost, and accessibility.

The research can be continued in the future on several fronts. One promising direction is the automation of the equipment by replacing the actuation system that uses a DC electric motor with a stepper motor and integrating a data acquisition system based on a force sensor (load cell) and an encoder to automatically record the force-elongation curve. Furthermore, the modular platform allows for the extension of testing capabilities, adapting the device to also perform compression or bending tests. Finally, extensive validation of the prototype through repeated tests on a variety of materials and specimen geometries is essential to consolidate the reliability of the results and to further improve the design.

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