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# EXPERIMENTAL AND SIMULATED MECHANICAL TESTS FOR POLYMERS MANUFACTURED BY 3D PRINTING

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**Abstract:** Additive manufacturing is one of the most disruptive technologies, as it is an efficient, sustainable process and with results very close to those achieved by subtractive manufacturing processes. In this context of innovation, this work aims to investigate the mechanical behavior of three materials produced via additive manufacturing (3D printing): ABS (Acrylonitrile butadiene styrene), PETG (polyethylene terephthalate glycol) and PLA (polylactic acid). Test specimens were printed in accordance with the ASTM D638 standard to carry out tensile testing of the materials and, subsequently, a computer simulation was carried out in order to corroborate the experimental data with the virtual data. It was observed that the information provided by the manufacturer of the filament used in printing is close, but there is a difference in resistance. Furthermore, analysis via the finite element method helped to elucidate more about the failure behavior of the materials.
**Keywords:** Tensile test. Computational Simulation. ABS. PLA. PETG.

## INTRODUCTION

The tensile test is currently widely used in industry, from the textile sector to metallurgical industries. The pieces on which the tests are carried out are called specimens, which follow standards, where the dimensions of the specimen are defined for each class of materials. Polymer test specimens follow the ASTM D638 standard.

Three-dimensional printing, or additive manufacturing (AM) – a broader term, has evolved a lot over its forty-year history. Currently, there are many types of printers and various types of filaments, thus having a wide area of application, enabling the printing of polymers, metals, resins and other materials. This process is gaining more and more strength in the market because it is practical equipment and because it is possible to make specific parts without the need to create a matrix (RANGEL et al, 2023), resulting in savings in time, resources and raw material, as there is little waste.

The printing of the specimens can be done with different types of filling, which will directly influence the results of the tensile test. For a more resistant specimen, the filling is increased, but it becomes more fragile, and if we configure a low filling, it will give us a weaker specimen, but on the other hand it will be more malleable (PIONHIEVICZ and FERREIRA, 2021).

With the help of Ansys it is possible to carry out different types of simulations, such as structural static analysis, which is used to carry out tensile tests using the software. This software is currently being widely used because its results are extremely close to reality, in addition to simulations, it provides an area for creating the design of the part to be analyzed (MAIA, 2023).

To carry out static analysis on a specimen, one end is fixed with a support and a displacement is added to the reverse end, then time is added to carry out the process. Once the test is complete, we can observe the neck whose test piece formed when it broke, we can know when it moved until it broke, the time it took, and the force needed to break it (MAIA, 2023).

Linked to disruptive processes, engineering uses computational technology to predict the behavior of materials in the face of loads and requests. Software that performs simulation using the finite element method (MEF), for example, are tools that help in the simulation of materials, mechanisms and mechanical components, in order to have a more reliable project.

Within the context of the above, the present work aims to reconcile results of tensile tests of materials produced by AM with results generated via Ansys, a *software* integrated with MEF, with the aim of understanding the mechanical behavior of the materials studied.

## THEORETICAL REFERENCE

This chapter aims to summarize the main subjects covered in the work, bringing the state-of-the-art of 3D printing technology, the use of polymeric materials and the importance of computational simulations within engineering.

### STATE-OF-THE-ART 3D PRINTING

For many years, 3D printing has not only been a tool for generating prototypes and has been used effectively as a production process in industry. As one of the pillars of industry 4.0, 3D printing – or additive manufacturing – finds a relevant space in contrast to typical, subtractive manufacturing. As summarized by Jandyal et al (2022), some of the main advantages are the saving of raw materials, the low level of waste, the production of complex geometries, which would be costly in the production of a specific mold or even impossible to obtain. in a conventional way, in addition to the high degree of automation.

Thermoplastic materials, ceramics, graphene-based materials and metals are some of the materials that can be obtained with 3D printing technology. Sharubudin, Lee and Ramlan (2019) mention that currently, 3D printing is widely used in mass customization and production of components in the fields of agriculture, health, automotive and aerospace industries.

Although the 3D printing process is sophisticated in the production of functional parts, Somireddy and Czekanski (2020) mention that its parameters influence the properties of the material, mainly in aspects regarding its homogeneity. One of the points is the anisotropy generated by the microstructure produced during the deposition of the layers. Anisotropy can be mechanical, electrical or thermal. The main one in printed components is mechanics (ZOHZI and YANG, 2021), which is the discrepancy of mechanical properties, such as the modulus of elasticity, according to the direction. This is due to the choice of the layer deposition plane (x, y and z axes). Anisotropy is reported in the literature by some researchers.

### POLYMERIC MATERIALS

The use of polymers in engineering has been favored by sustainable processes, which focus on saving energy and raw materials. Within the context of additive manufacturing, polymers are the first option, due to their ease of operation and high availability on the market, which is generally in the form of extruded filaments.

One concern about the use of plastics is its impact. In this regard, PLA has a carbon footprint equivalent to half that of polymers derived from fossil fuels, but this value continues to decrease and may eventually reach almost zero, according to Joseph et al (2023), which makes it attractive on the market. for applications that consider biodegradability. Besides, according to what was reported by Joseph et al (2023), the PLA market and, more specifically, its use in 3D printing must continue to grow worldwide. One of the concerns with PLA is its low resistance to high temperatures (PERNICA et al, 2021).

In addition to PLA, another widely used option when it comes to filaments for 3D printing is ABS, a copolymer composed of acrylonitrile, butadiene and styrene, used in various applications, ranging from toys to automotive components. ABS is quite susceptible to shrinkage during printing (PERNICA et al, 2021), so additional care is required. Unlike PLA, it is not biodegradable and the way to reduce its impact is by recycling.

PETG is a polymer that is an excellent material for extrusion, blow molding and thermoforming, as well as a popular choice in additive manufacturing in recent years).

## COMPUTER SIMULATIONS

Computer simulations are research techniques that help to reproduce results that are close to reality, using the analysis of processes through computer programs to understand and predict their behavior, without the need to use a physical experiment in reality, which for many it becomes unfeasible or at a high cost.

To assist in the study and conclusion and/or comparison of results, the Ansys *software* is used, in the *Static Structural* analysis mode (VACCARO, 1999; CASSEL; VACCARO, 2007).

## METHODOLOGY

Initially, the specimens were modeled using the CAD software Solidworks. Following the preparation of the test specimens in the 3D printer, the files were imported in STL format, for subsequent printing following specific ASTM D638 standards for the desired test. In this study, three different materials were analyzed, PLA, PETG and ABS. In total, nine specimens were prepared, three of each material to carry out the tests in triplicate. In **Figure** 1 it is possible to see the equipment that was used to print the test specimens. It is a 3D printer model K1 Max year 2023 from the manufacturer Creality.

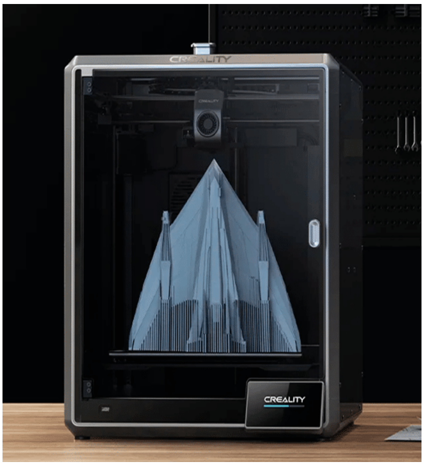


Figure 1: K1 Max Printer

Source: the authors (2023).

In **Figure 2** you can see the image of the test specimen in the 3D printer viewing environment.

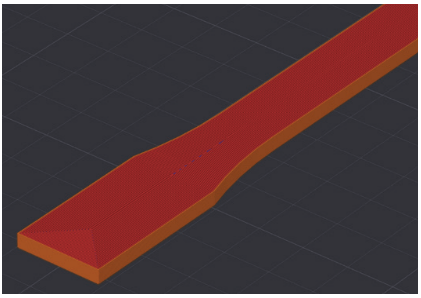

Figure 2: K1 Max printer test specimen image.

Source: the authors (2023).

**Table 1** presents the parameters used in the manufacture of test specimens of ABS, PETG and PLA materials through 3D printing.

| Parameter | ABS | PETG | PLA |
|---|---|---|---|
| Temperature (ºC) | 240 | 235 | 205 |
| Speed (mm/s) | 50 | | |
| Flow | 100% | | |
| Layer height (mm) | 0,2 | | |
| Nozzle diameter (mm) | 0,5 | | |
| Extrusion width (mm) | 0,52 | | |
| Fill | 100% | | |
| Fill Pattern | Concentric | | |

Table 1: Printing parameters of the test specimens

Source: The authors (2023).


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After the specimens were prepared, they were subjected to a tensile test on the universal tensile machine model 34TM-50-SA from the manufacturer Instron, which can be viewed at **Figure 3**.


Figure 3: Instron universal traction machine with 50 kN capacity.

Source: the authors (2023).

To carry out the tensile test, a clamping claw with a capacity of 5 kN was used to fix the specimens. After fixation, the test was carried out by applying uniaxial traction force until the material ruptured, at a speed of 50 mm/min. All materials were tested in triplicates. After carrying out the tests, all parameters were compiled in order to record the information from the tests and compare with the next stage, which is the analysis of the behavior of these materials in simulation software. With the results, it is expected to compare the data provided by the supplier for the raw material and also the results obtained in the simulation *software*.

To carry out the simulation, we used the *software* Ansys, with a Static Structural type analysis and for the test the following parameters were used as **Table 2**.

| Parameters | ABS | PETG | PLA |
|---|---|---|---|
| Poisson's ratio | 0,33 | 0,38 | 0,39 |
| Young's Modulus (MPa) | 1335,9 | 1067,9 | 1896 |
| Yield Limit (MPa) | 14,7 | 18,6 | 24,8 |
| Tensile Strength Limit (MPa) | 29 | 32,6 | 46 |
| Traction Force (N) | 1400 | 1600 | 2400 |

Table 2: Parameters for numerical testing in Ansys

Source: the authors (2023).

## ANALYSIS AND DISCUSSION OF RESULTS

The printed specimens can be seen in **Figure 4**, where they have an identical format according to the printing standard for tensile testing, but they show different colors due to their characteristics and chemical composition.

Figure 4: Black (PLA), yellow (ABS) and white (PETG) test specimens

Source: the authors (2023).

In **Figure 5**, we can see the tension x strain graphs obtained by the traction machine in the tests carried out with the three polymers.

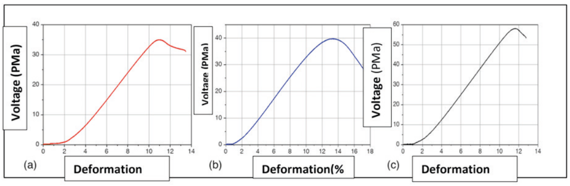


Figure 5: Stress-strain diagrams for printed materials, (a) ABS, (b) PETG and (c) PLA

Source: the authors (2023).

In **Table 3** below, the resistance and deformation limit data obtained in the tensile test are shown.

| | Strength Limit (MPa) | Elongation at break (%) |
|---|---|---|
| ABS | 34,04 ± 1,33 | 13,47 ± 1,57 |
| PETG | 39,69 ± 0,47 | 17,07 ± 0,17 |
| PLA | 58,10 ± 0,23 | 12,89 ± 0,58 |

Table 3: Results obtained from the tensile tests carried out

Source: the authors (2023)

In **Figure 6**, the ruptured specimens at the end of the tensile test can be seen, where we can analyze that the rupture follows a pattern, depending on the materials and the way the body was printed.

Figure 6: Specimens after the experimental tensile test.

**Source:** The Authors (2023)

Using computer simulation, the tensile strength limit results were obtained, **Table 4**, which allows us to draw conclusions and make a comparison with the results obtained experimentally.

| | Tensile Strength Limit (MPa) |
|---|---|
| ABS (Figure 7) | 34,19 |
| PETG (Figure 8) | 40,38 |
| PLA (Figure 9) | 53,70 |

Table 4: Results obtained in computer simulations

**Source:** the authors (2023).

The values presented in the table were obtained at the location closest to the rupture point of the test specimens, shown in **Figures 7, 8 and 9**.

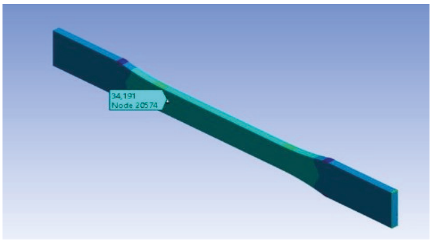

Figure 7: Ansys simulation of the ABS traction test

**Source:** the authors (2023).

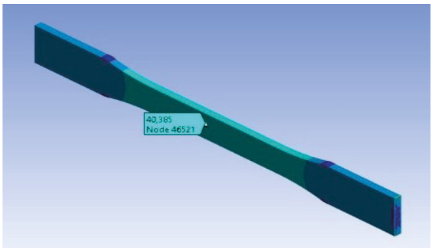

Figure 8: Ansys simulation of the PETG tensile test

**Source:** the authors (2023).

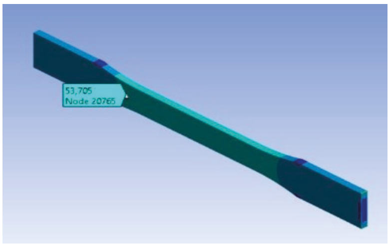

Figure 9: Ansys simulation of the PLA tensile test

**Source:** the authors (2023).


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## CONCLUSION

The combination of traction tests, advanced 3D printing and computer simulations gives us results close to the real ones, and can give a perspective very close to the tests on the universal traction machine. In theory, the combination of experimental tensile testing and software simulation represents a comprehensive and effective approach to understanding the mechanical behavior of materials. The union of these two methodologies offers a complete view, combining the practical experience of the machine with the analytical vision that Ansys provides, resulting in a more accurate assessment of the analyzed specimens. After the experimental traction tests of PLA, PETG and ABS, together with the results shown by the Ansys software, it is concluded that the results are very clear, therefore, it can be said that the objective was successfully achieved.

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