

COB-2023-1916 TECHNOLOGICAL TESTS ON ABS SPECIMENS

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Abstract. *The three-dimensional parameterized prototyping is a fundamental technology for the free fabrication of objects. It is used in manufacturing, commercial, academic, and domestic environments and allows the wide production of parts in pilot or real scale, with potentially low values and increasingly smaller, if compared to alternative manufacturing methods. It presents greater recurrence in medicine, biology, and engineering. Studying the behavior of raw materials used for 3D printing is a valuable tool to understand and develop more efficient models according to the application. It is possible to collect mechanical data through tensile strength tests using a universal machine and test specimens of different materials and printing configurations. ABS material is the lowest cost on the market, presents excellent cost-effectiveness and requires some skill for plotting. PLA is a widely commercialized material, requires less skill in operation and has greater mechanical flexibility. The development is permeated using a GTMax 3D H4 Core 3D Printer for plotting the CP's and the consequent use of the Universal Machine for Tensile tests. It's important to mention that every machinery is available at IFSP. The viability of the project lies in achieving the objectives of comparing the mechanical resistance of the materials, with values obtained at the maximum tension of 19 MPa and comparing them with commercial values and those predicted in the literature.*

Keywords: 3D printing, ABS, PLA, hydraulic, technological tests.

1. INTRODUCTION

According to (Xu et al., 2021), it is possible to prototype models of structures on reduced scales, using 3D printing, to prepare tests and studies and compare practical values with theoretical values and simulations in structural analysis software.

According to the state of the art on the use of 3D printing in engineering, it is possible to observe recurring application in the areas of hydraulics, biofabrication and tissue engineering and also to highlight the approaches regarding the efficient reproduction of bone and soft structures, hydraulic structures, and biological bridges. In this scenario, there is an exchange of prototyping parameters covering different applications and technology disciplines, which indicates the vast field of research.

The importance of this work is justified by the discussion on the modeling and manufacturing of test specimens using 3D printing, with the aim of preparing mechanical tests and studying the behavior of the material based on the variation in molten filament deposition and comparing the data with theoretical values.

2. LITERATURE REVIEW

Prototyping is a universal and constantly evolving area, for this reason, knowing the state of the art of the subject allowed us to identify research gaps and trends. Just as (Lopes & Marques, 2023) they used bibliometrics to know the state of the art about the use of Pressure Reducing Valves, the present study was carried out through bibliometric, qualitative, and quantitative analysis about three-dimensional printing.

From the research of secondary data in the “Scopus” database, belonging to the company *Elsevier*, with the keywords: *3D Printing, engineering and hydraulic* and without temporary delimitation, 36 works were obtained located between 2008 and 2023, with emphasis on the year 2019 with the largest number of works (8) and the United States and China, the countries with the highest number of documents, both with 8 publications.

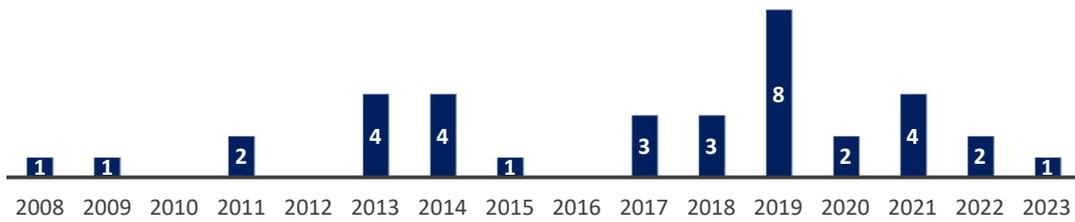


Figure 1. Publications by year.

The search result presents thirty-six works, indicating the scarcity of publications in the field of engineering correlating 3D printing and hydraulics and highlights the knowledge gap. The engineering area was the one with the highest number of works, totaling twenty-four.

With data from Base *Scopus*, a density chart was created correlating in clusters, keywords, and authors, according to recurrence in publications. The first cluster generated is red in color and is composed of 3d printers, 3d printing and fabrication and the second, in green color, is composed of hydraulic structures, tissue engineering and scaffolds (biology).

In this way, the clusters indicated two lines of research, the first being directly aimed at printing and 3d printers and the second referring to the most recurrent applications such as hydraulic, biological, and biomedical structures.

When analyzing the keywords by the years of publication, three periods were highlighted and present the following lines of research: from 2008 to 2011, the works discussed the rates of deformation in three-dimensional printing, from 2012 to 2017, they dealt with equipment, manufacturing techniques and the risks present, and from 2018 to 2023, biomedical applications. Thus, the linearity of the academic discussion can be noticed, starting with the characteristics and parameters of 3d printing, followed by discussions on techniques and equipment for printing and, finally, the lines of research and applications.

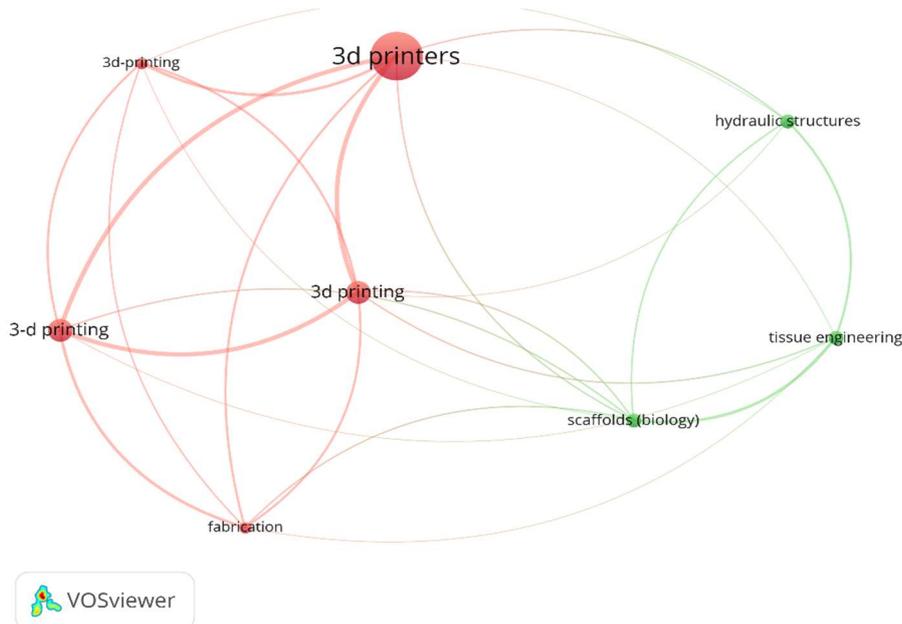


Figure 2. Keyword groupings.

The figure below illustrates two networks of authors that were grouped by line of research and Dr. Elkem Vorndran is the bridge between sets, in the line of research in biofabrication.

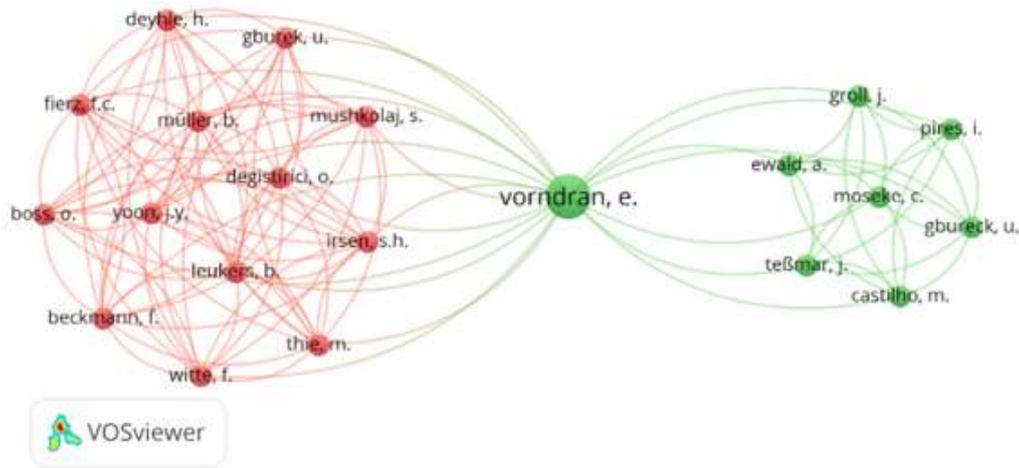


Figure 3. Groupings by authors.

Highlighted in the grouping in red are Deyhle, Gburek, Fierz, Muller, Mushkolaj, Degistirici, Boss, Yoon, Irsen, Leukers, Beckmann, Thie and Wittte, who correlate for publishing in the biomedical area and the second set, in green color, are Vorndran, Groll, Pires, Ewald, Moseke, Gbureck, Teßmar and Castilho. It should be noted that the authors in green color, prepared the work entitled "Direct 3D powder printing of biphasic calcium phosphate scaffolds for substitution of complex cap defects" which deals with the use of 3D printing with a mixture of water binder and cement powder, in the production of individual and complex bone substitutes.

Created in 1985 by Charles Hull, stereolithography is considered the precursor technology of 3D printing. Also known as additive manufacturing, it is characterized by manufacturing objects in gradual layers, based on digital models. (Oertel & Shen, 2022)

According to Oertel and Shen (2022), prototyping allows the reproduction of complex structures on a pilot scale, enabling studies of hydraulic phenomena. The authors point out that printed models can demonstrate greater efficiency and viability, when compared to models of alternative technologies, which have less accuracy.

Oertel and Shen (2022) when reproducing dam models on a laboratory scale, they varied parameters of layer heights between 0.4 mm and 0.6 mm, vertical and horizontal filament deposition orientations, and tested the models under equivalent hydraulic conditions. The conclusions obtained were the insignificant influence for impression thickness up to 0.4 mm and above, surface irregularities are accentuated; the other parameter changes did not show disparity in hydraulic performance, indicating deviations of less than 5%.

(Xu et al., 2021) deal with the prototyping of two models of porous and cylindrical structures, with parameters analogous to bone tissue scaffolding models, for comparison of real and virtual structural performance. The ABAQUS software, which elaborates Finite Element Analysis (FEA), was used to simulate resistance to compression, shear, and torsion. Obtaining values of 1.1 MPa of compression with 7% of deformation, the authors concluded that the unit cells with spherical pores better distribute the stress in relation to the model with cylindrical poles.

Sasaki et al. (2022) deal with the reproduction of soft and bony structures, based on Computed Tomography (CT) and using three-dimensional printing. The authors point out the efficiency in the manufacture of the parts and the importance of using them in the teaching of ophthalmology, as they claim that the anatomical parts had their characteristics reproduced, even with slight losses.

To verify the influence of the filling pattern on 3D prints, Jardim and Marques (2020) they designed and tested Specimens (CP) following ASTM D638-14 standards. The CP's filling pattern was the only variation and the parameters used were tri hexagon (TH), grid (GR), cubic (CB), triangle (TR) and gyroid (GY).

Jardim and Marques (2020) with the use of ABS as raw material, they obtained the highest tensile strength at 33.64 kgf and maximum tension of 20.59 MPa, with the gyroid pattern and the lowest value at approximately 30 kgf and maximum tension of 19.16 MPa, with the cubic pattern. The maximum stress value (20.59 MPa) compared to the value informed by the manufacturer (40.2 MPa), represents approximately 50% and although the difference is expressive, the authors justified the disparate value due to the completion of CP's with only 50% and emphasized that the literature deals with rates of comparisons with greater disparity, when using 50% of filling in the specimens.

According to (Canevarolo Júnior, 2006), ABS is a copolymer that originates from the reactions Acrylonitrile, Butadiene and Styrene and, as it is derived from petroleum, it gives off toxic gas if exposed to high temperatures and is not biodegradable.

The ABS composition may vary for each reaction. Acrylonitrile can vary between 15 and 35% and provides thermal efficiency and chemical resistance to the composition; Butadiene varies between 5 and 30% and provides flexibility and

resistance to impact and Styrene, comprises between 40 and 60% and guarantees workability in processing, a shiny finish and rigidity (Harper, 2002).

According to Santana et al. (2016) PLA it is a thermoplastic, non-toxic, biocompatible, and biodegradable. Material whose origin is related to the family of aliphatic polyesters, poly (α - hydroxy -acid), is characterized as a biopolymer and is composed of lactic acid, present in corn starch, potato starch and sugar cane.

3. GOAL

This work aims to model and prototype test bodies in ABS and PLA, in accordance with ASTM D638-14, carrying out tensile strength tests and comparing the materials and values provided by filament manufacturers.

4. METHODOLOGY

The materials and methods used in the development of the work are divided into two phases. The first covers the modeling of the specimens (CP) with the REVIT tool present in the BIM concept and the printing using the GT Max 3D H4 Core printer, with ABS and PLA filaments. The second part includes the tensile strength tests through Universal Testing Machine, for comparison of materials, printing settings and theoretical values.

To carry out the mechanical testing of materials, the ASTM D638-14 standard was chosen, which is widely used to evaluate the tensile strength and elongation properties of plastic materials, in rigid, non-rigid, semi-rigid and composite reinforced. It is important to highlight that these standard covers analysis of specimens under different conditions, such as varying temperatures, deformation speeds and different types of specimens.

The modeling of the CP is done according to the norm “Standard Test Method for Tensile Properties of Plastics 1”, ([s.d.]), which characterizes the specimen in the preferential type I of rigid plastic. Based on this definition, the ASTM D638-14 standard determines that the part must have the following configurations: Total Thickness (T) 7 mm, Length (LO) 165 mm and Overall Width (WO) 18 mm, Narrow Section Length (L) 57 mm and Narrow Section Width (W) 13 mm. The design of the piece is shown in the figure below.

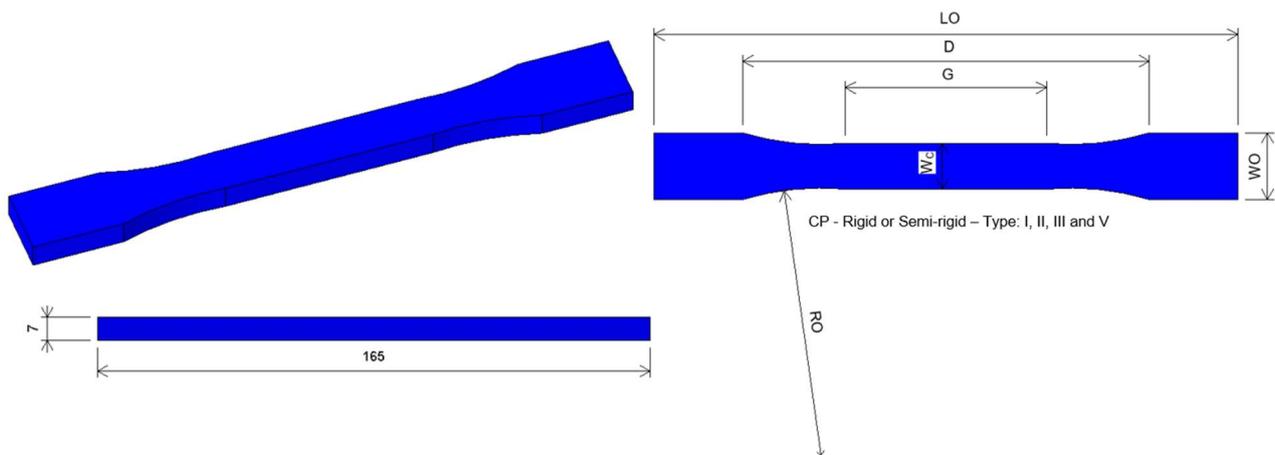


Figure 4. Type I Test Body.

With the project elaborated in real scale 1:1, the model is exported from the REVIT Software, in STL format, so that the Ultimaker Cura digital slicer parameterizes the printing according to the printer, filament, quality and resistance of the piece. As the parameterization of the part aims at better mechanical behavior and lower aesthetic performance, thicker layers, and filament deposition walls and in smaller quantities are chosen, thus creating fewer points of mechanical vulnerability, allowing greater resistance.

In this scenario, 99%-part infill, wall height at 0.4mm, and 0.8mm thick is applied. The deposition pattern used is in lines, at 240 °C and on a table heated at 100 °C for ABS and PLA, 200 °C of extrusion, on a table heated at 60 °C, both with filament flow at 105% and speed of 50 mm/s.

It should be noted that to delay the cooling of the ABS part, expose it to a high extrusion temperature and keep the extruder coolers turned off, as the material undergoes rapid heat loss and results in early shrinkage of the part, which impairs printing and final quality. In this way, the filament flow at 105% and at low speed, help to avoid under-extrusion and provide better conditions for printing and the model.

To contribute to the fixation of the part on the printing plate during the entire plotting, filament adhesive is applied to the plate and the adhesion of the part on the table is configured, with the “BRIM” option. The filament deposition needs to be done in three different axes of the part so that the best mechanical performance can be observed depending on the

deposition. In this context, five units are manufactured for each direction of deposition, maintaining the standards. You can see the slicing of the pieces in the image below.

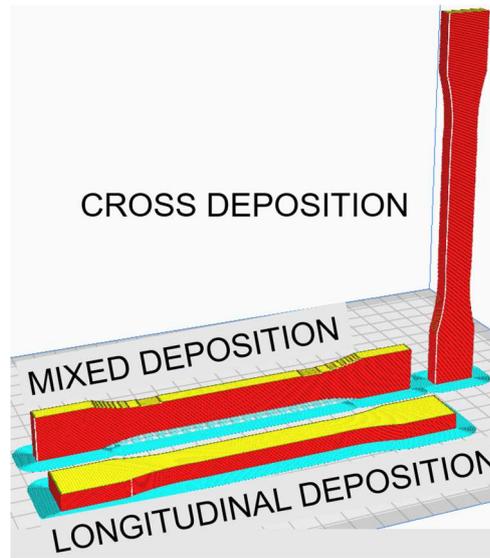


Figure 5. CP's slicing.

Finally, the models are printed on the printer, transporting the file in “gcode” format via a sd card.

With the specimens manufactured, the models are tested using the Universal Testing Machine. The different tests have the objective of comparing the resistances obtained and tracing parameters according to printing settings and dissimilar materials.

5. RESULTS AND DISCUSSIONS

In the following image there are models of CPs in ABS and PLA. It should be noted that the PLA chosen is HT and natural color to prevent the filament dye from influencing the mechanical performance.



Figure 6. Type 1 Test Specimens - ABS and PLA.

Raising the filament flow to 105% was efficient in providing excess extrusion points and the reliefs in lighter tones are the evidence of this framing.

With part of the CP's manufactured, it was possible to perform a tensile strength test in an Universal Test Machine, following parameters of the ASTM D638-14 standard and can be seen in the following image:

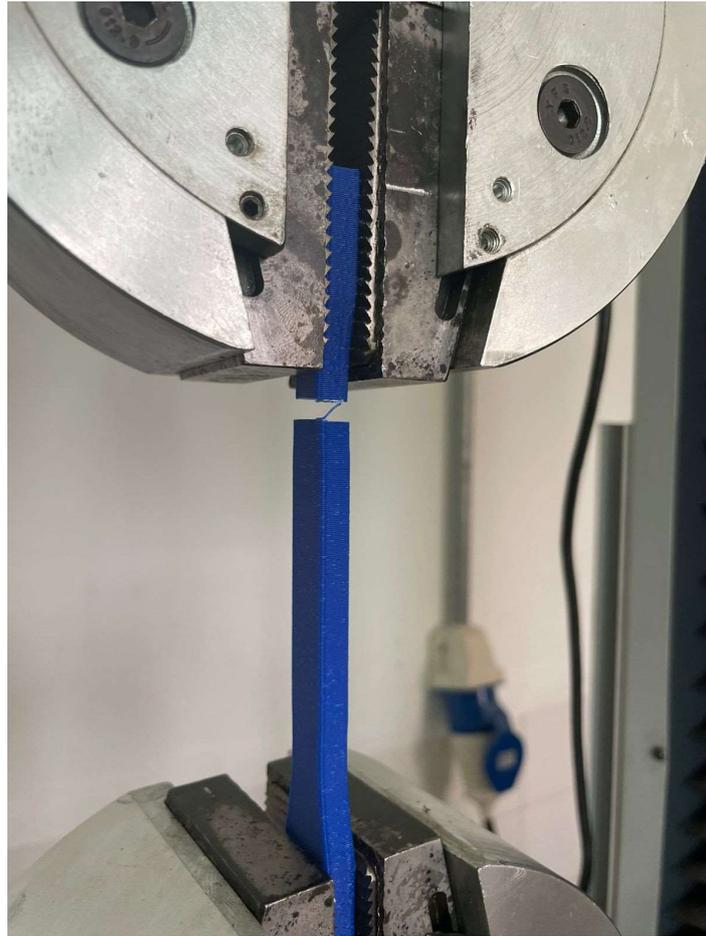


Figure 7. Tensile Strength Test.

The maximum stress obtained from ABS was 2400 N (as illustrated in the figure below) and highest tensile strength at 19 MPa, and represents a fair value compared to the value indicated by the manufacturer of 448 kg/m² and compared to the value found in the literature, approximately 20 MPa. (Jardim & Marques, 2020).

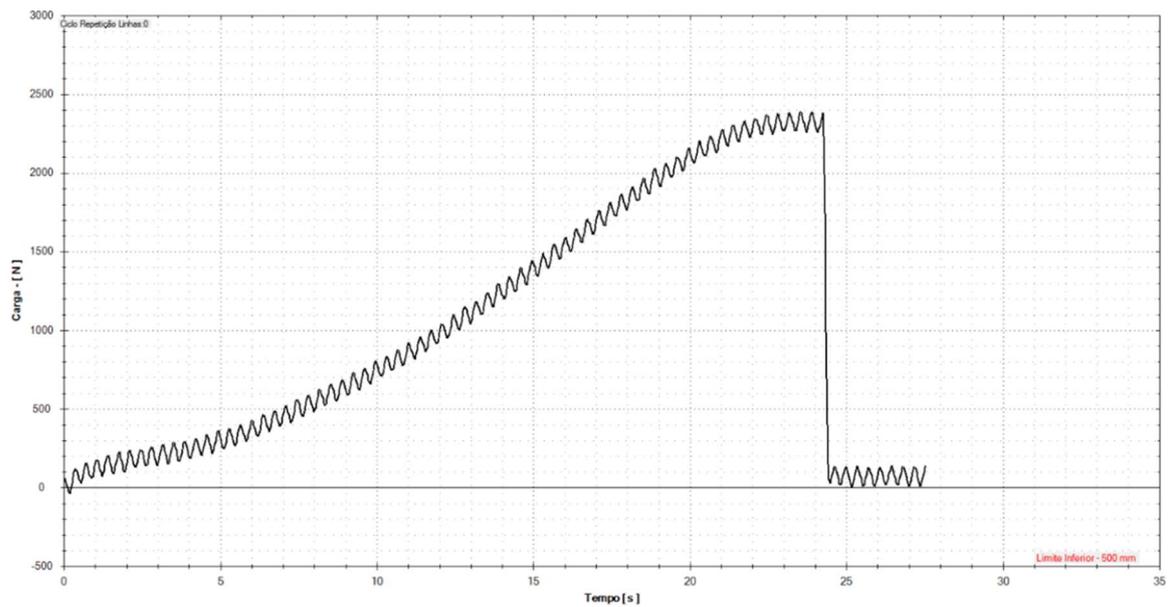


Figure 8 Higher Stress CP ABS Analysis.

Although the tendency for better mechanical behavior is given to ABS, the PLA material had the maximum tensile strength value obtained at 35.2 MPa and the highest applied tension at 4430 N (as illustrated in the figure below), which represents a positive result and higher than the value obtained from the ABS material.

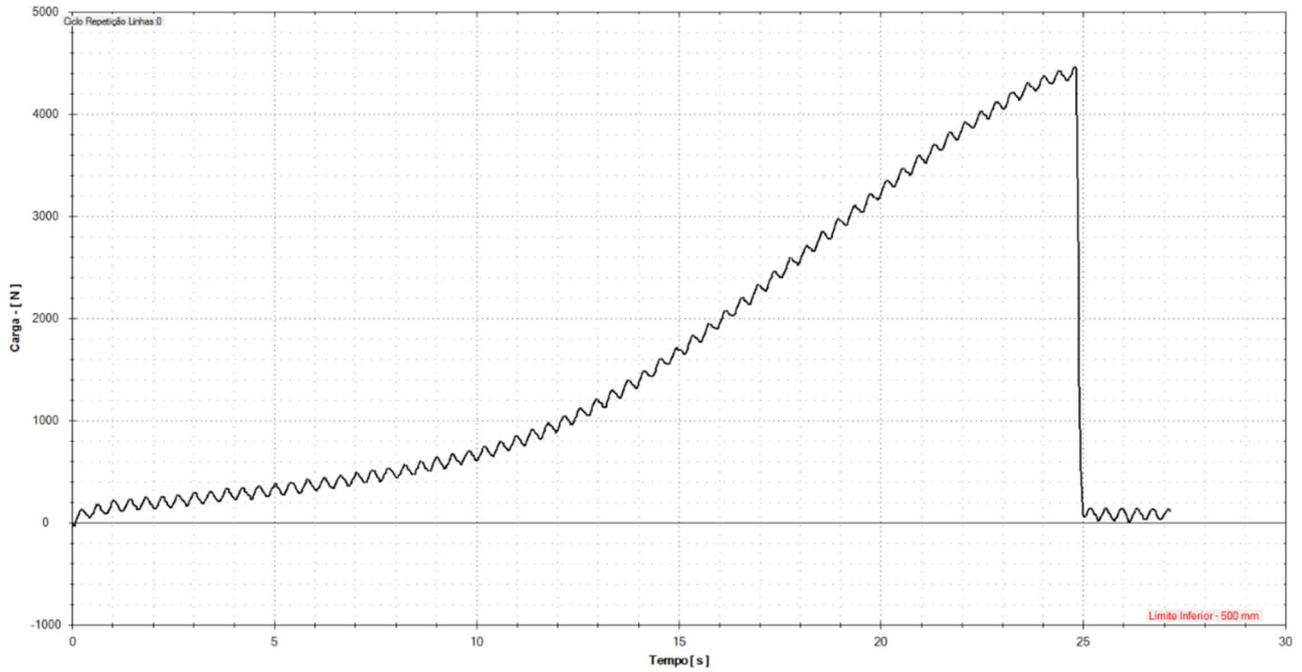


Figure 9 Higher Stress CP PLA Analysis.

The following figure shows the average tensile strength values achieved, depending on material and type of deposition.

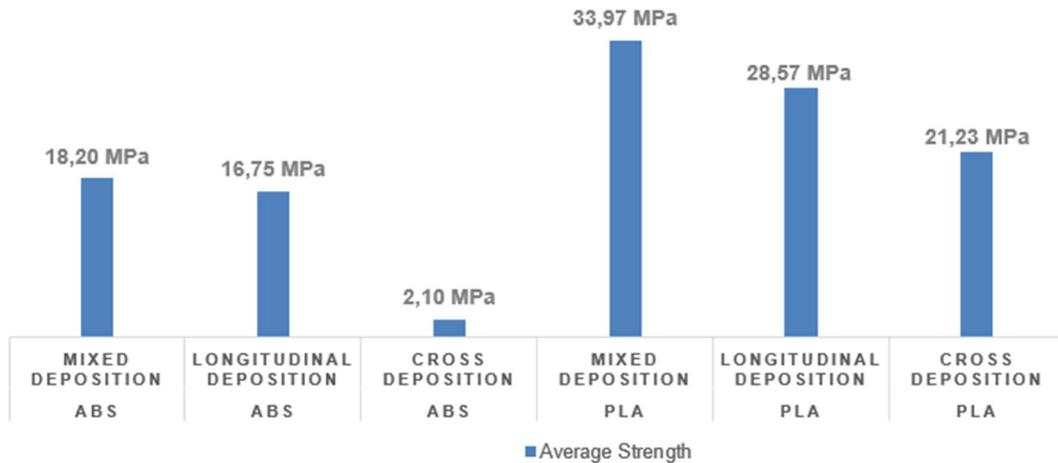


Figure 10 Tensile Strength Values.

It should be noted that, although five specimens were manufactured for each type of filament deposition and their corresponding material variation, to calculate the average maximum tension and maximum resistance obtained, three values were used and two were discarded due to the variation. minimum in the data between the specimens. This indicates good consistency in manufacturing and testing.

Figure 11 shows the average values of stresses applied to the specimens, depending on the material and type of deposition.

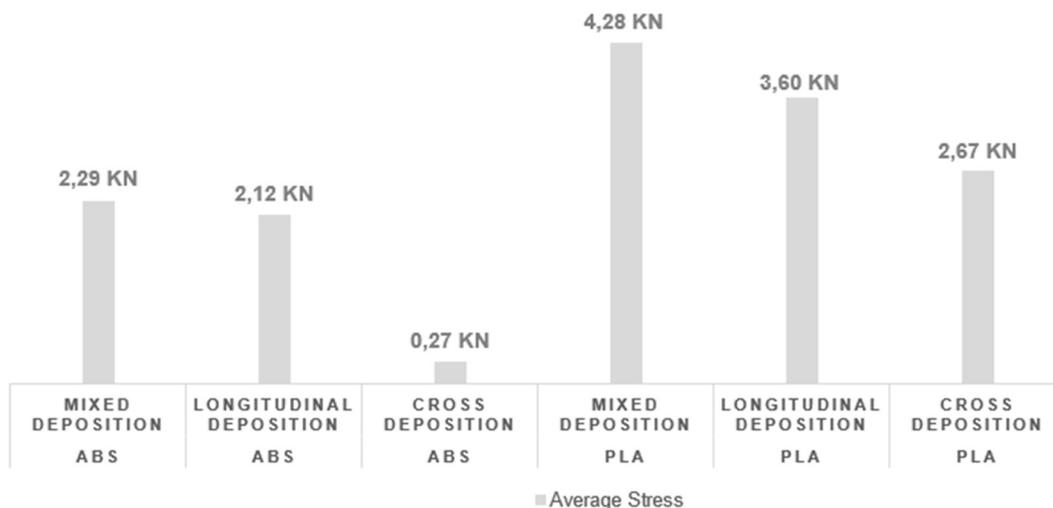


Figure 11 Stress Values.

According to the analysis of the tensile strength values, the efficiency of the deposition of “mixed” type material can be observed due to the higher values achieved, both for ABS and PLA materials. This characteristic is justified by the fact that there are fewer layers of filament and consequently a smaller area of adhesion between layers.

In this context, the lowest resistance values obtained were given to specimens with transverse filament deposition, and these are characterized by containing the greatest number of layers. It is also important to highlight that this orientation directly contributes to the collapse of the part, as unlike longitudinal depositions, where stresses act axially on the molten material, in transverse deposition the action of the force focuses on a direction perpendicular to the adhesion area between layers.

6. CONCLUSIONS

Based on the development of this work, it is possible to affirm that three-dimensional printing technology is effective in producing real-scale scenarios, which allows the creation of complex studies.

It can also be concluded that it is possible to prototype parts with different applications and verify their respective mechanical behavior, as well as the characteristics of the materials used.

It is important to highlight the influence of the deposition of molten material on the mechanical characteristics of the object. This is because specimens with fewer deposition layers, aligned parallel to the direction of force application, demonstrated superior mechanical performance compared to specimens with more deposition layers, arranged perpendicular to the force.

7. ACKNOWLEDGEMENTS

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