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MECHANICAL ANALYSIS OF PARTS MANUFACTURED THROUGH 3D PRINTING CAST FILAMENT MANUFACTURING (FFF) TECHNOLOGY

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Abstract: This work presents the study of the mechanical properties of tensile strength in specimens produced by the 3D printing process known as Fused Filament Fabrication (FFF). The specimens were printed with polylactic acid plastic material (PLA), with filling variations of 25%, 50% and 100% and with rectangular and honeycomb printing geometries. It was proved through the traction test that as the filler increases, the resistance limit increases. It was also verified that the honeycomb printing geometry presents more resistance than the rectangular one.
Keywords: Mechanical properties. FFF. PLA. 3D printing.

INTRODUCTION

3D printing, also known as additive manufacturing, is the process by which physical objects are created by layering materials based on a digital model. All 3D printing processes require software, hardware, and materials to work together. The most common 3D printing methods are: fused filament fabrication (FFF or FDM), stereolithography (SLA) and selective laser sorting (SLS) (AUTODESK, 2018). Currently, the use of FDM (Fused Deposition Modeling) technology has become common. It produces conceptual models, functional prototypes, and end-use parts in standard, engineering, and high-performance thermoplastics. This use makes the potential growth of this process and technology predictable.

According to Produteca (2018), one of the main reasons for this growth is the production industry that has been adopting 3D printing as a viable alternative to traditional manufacturing methods, both for the production of prototypes and for the final products.

The FFF 3D printer, illustrated by Figure 01, produces objects layer by layer, that is, by overlapping, as shown in Figure 02. The additive manufacturing technique system creates objects using various materials such as resins, ceramics, plastics and even human and human tissues. foods. Most of the time this type of printer uses a thermoplastic filament that is heated until it reaches its melting point and then extruded layer by layer until it becomes a three-dimensional object. The developed objects start as a 3D design (CAD - *computer aided design)* file on a computer. Before it can be printed, the CAD file must be converted into a format supported by the 3D printer. Compared to other 3D printing methods like stereolithography or selective laser sintering, the FDM process is a bit slower. (WHISHBOX TECHNOLOGIES, 2018).

Figure 01 – 3D printer - FDM process

Source: Sethi 3D, 2019.

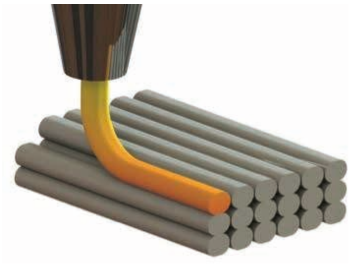

Figure 02 – Layered print layout

Source: Good 3D Printing, 2019.

According to Callister and Rethwisch (2012), thermoplastic polymers have linear and branched structures. They soften when heated and harden when cooled.

Among the thermoplastics most used in

the FFF process, the following stand out: PLA, acrylonitrile butadiene styrene (ABS) and polyethylene terephthalate with glycol addition (PETG). One of the materials used in this process is PLA, a synthetic thermoplastic polymer that has been replacing conventional plastics in several applications. To give you an idea, it can be used in food packaging, cosmetic packaging, market plastic bags, bottles, pens, glasses, lids, cutlery, jars, cups, medical devices, non-woven fabrics, and also used as a printing filament. 3D (ECYCLE, 2018). According to 3DLAB (2018), PLA has good mechanical properties and has two drawbacks: low resistance to impact and high temperature. It supports higher static load, when compared to ABS and PETG, 2150 N, or approximately 215kgf. However, it does not have great deformation before failure, that is, it is not very ductile. It has an elastic modulus of 4350 MPa and a yield strength of 66 MPa.

With the increase in the use of FDM technology, both in the industrial area and in domestic use, it is necessary to evaluate the physical properties of resistance of the parts produced in this process, in view of the variation in filling and the orientation of the printing layers. The choice of adequate filling will avoid oversizing or making parts with insufficient parameters for the mechanical requirements for which they are intended.

Thus, this work aims to experimentally evaluate the mechanical property of PLA used in the manufacture of parts, as well as the incidence of mechanical properties of different types of filling and layer orientation.

METHODOLOGY

To carry out the experimental procedure, the organizational structure is shown in Figure 03.

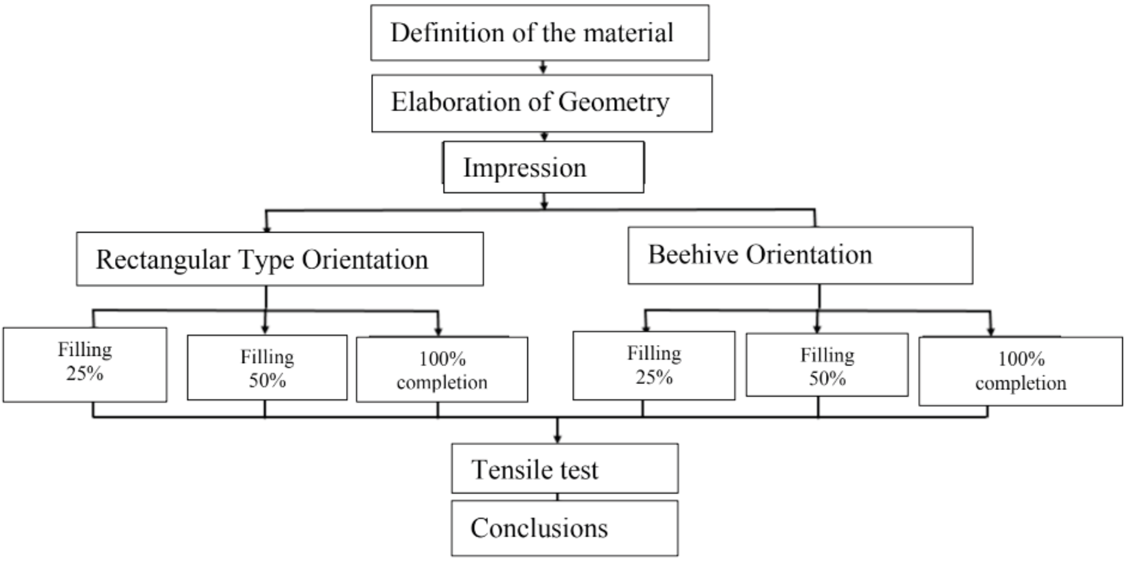

Figure 03 – flowchart

Source: Authors

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MATERIAL

For printing, PLA Basic filament with a diameter of 1.75 mm, sold by the company 3D Fila, is used. According to 3DLAB (2018), the mechanical properties of PLA are as shown in Table 01:

PLA Properties – Grains	
Density	1,24 [g/cm³]
Melting temperature	185 [°C]
Flow voltage	66 [Mpa]
Flexural strength	130 [Mpa]
Modulus of elasticity	4350 [Mpa]
Traction Test Result according to Standard ASTM D 638 - Printed Test Piece	
Flow voltage	24,8 [Mpa]
Modulus of elasticity	1896 [Mpa]
Tension of rupture	46 [Mpa]
Stretching	3,69 [%]

Table 01 – Mechanical properties of PLA

Source: 3DLAB, 2018 (Adapted).

GEOMETRY

According to Letcher and Waytashek (2014), the geometry of the specimens obeys standardized dimensions for each type of mechanical test. In the tensile test, the geometry is given by Figure 04:

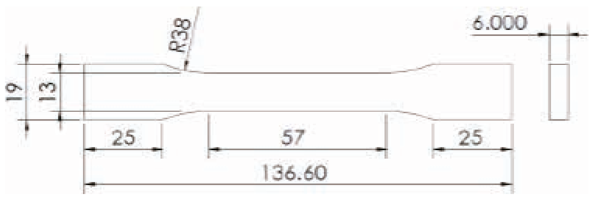


Figure 04 – Specimen for tensile testing, dimensions in millimeters.

Source: LETCHER e WAYTASHEK, 2014.

For modeling the specimen, the SolidWorks 2015 software is used.

PRINTING

The dimensional printing and identification parameters of the samples are arranged according to Table 02:

Rehearsal	Traction														
Impression Geometry	Rectangular						Hive						Rectilinear		
Fill	25%	25%	25%	50%	50%	50%	25%	25%	25%	50%	50%	50%	100%	100%	100%
Test Body Nomenclature	TR 1			TR2			TC 1			TC2			TRC 1		

Table 02 – Dimensional Printing Parameters and Sample Identification.

Source: Authors.

Prints are made with rectangular, honeycomb and rectilinear printing geometries, as shown in Figure 05, Figure 06 and Figure 07:

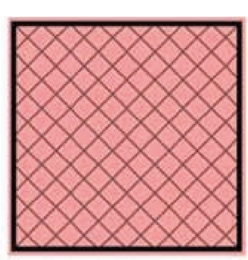


Figure 05 – rectangular printing geometry

Souce: 3DLAB, 2018.

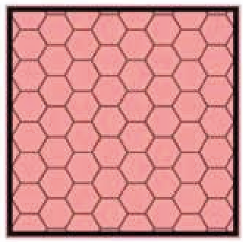


Figure 06 – Honeycomb printing geometry

Source: 3DLAB, 2018.

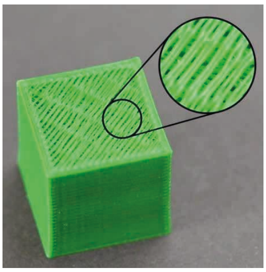


Figure 07 – Rectilinear Print Geometry

Source: 3D ALL BRAZIL, 2019.

The printer used to print the specimens is the Prusa I3 MK3S, manufactured in 2018, illustrated in Figure 08.

Figure 08 – Printer Prusa I3 MK3S

Source: Prusa Research, 2019.

For printing, the parameters shown in Table 03 are used:

PRINTING PARAMETERS (RECOMMENDED BY THE MANUFACTURER AND USED)		
PARAMETERS	**RECOMMENDED**	**UTILIZED**
PRINT SPEED:	40-180 mm/s	160 mm/s
TABLE TEMPERATURE:	inferior a 60°C	50°C
PRINT TEMPERATURE	180 a 210°C	200°C
LAYER HEIGHT	-	0,2 mm

Table 03 – Print Parameters

Source: Authors

The printed specimens are numbered for the purposes of organization and accuracy in obtaining data. The numbering was in accordance with Table 03. Horizontal lines were also made on the specimens, as shown in Figure 09, to visually follow the elongation during the test.

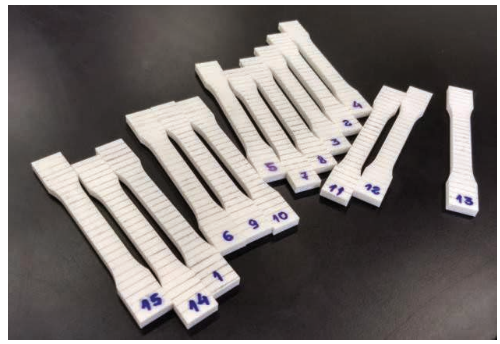


Figure 09 – Printed Bodies of Evidence

Source: Authors

TRACTION TEST

In the tensile test, the specimen is subjected to loads in opposite directions, perpendicular to the cross section of the specimen, as shown in Figure 10, tending to elongate the material until it ruptures, identifying the normal stress limit that the structure supports.

Figure 10 – Traction Test

Source: LETCHER and WAYTASHEK, 2014.

The specimens tested followed standardized dimensions, as shown in Figure 04 (LETCHER and WAYTASHEK, 2014). To carry out the tensile test, the SHIMADZU model SSM-DAK-5000N equipment was used, as shown in Figure 11. This test was carried out in the mechanical tests laboratory of the Federal University of Minas Gerais.

Figure 11 – Shimadzu SSM-DAK-5000N Traction Test Equipment.

Source: Author.

RESULTS AND DISCUSSIONS

In the test carried out, the force acting at that instant and the elongation of the specimen were recorded in a fraction of 0.1 second. Based on this, it was possible to analyze the behavior of the printed structure during the tensile test, determining points such as the tensile strength limit and total elongation of the specimen. According to Table 02, three specimens for each group were used to calculate the arithmetic mean and standard deviation of the results obtained. The results obtained were transcribed according to Table 04:

NOMENCLATURE	TEST BODY NUMBER	% FILLING	FILLING GEOMETRY	FINAL LENGTH (mm)	RESISTANCE LIMIT (Mpa)	RESISTANCE LIMIT (N)
TR1	1 2 3	25%	Rectangular 	(139,89±0,49)	(17,19±0,55)	(1340,93±42,91)
TC1	4 5 6	25%	Hive 	(139,83±0,32)	(19,97±0,66)	(1557,42±51,12)
TR2	7 8 9	50%	Rectangular 	(138,94+0,25)	(21,97±0,32)	(1713,44±25,20)
TC2	10 11 12	50%	Hive 	(139,99±0,45)	(25,19±0,60)	(1964,52±46,82)
TRC1	13 14 15	100%	Rectilinear	(141,92±0,81)	(38,09±0,77)	(2970,95±60,20)

Table 04 – Results of Traction Tests.

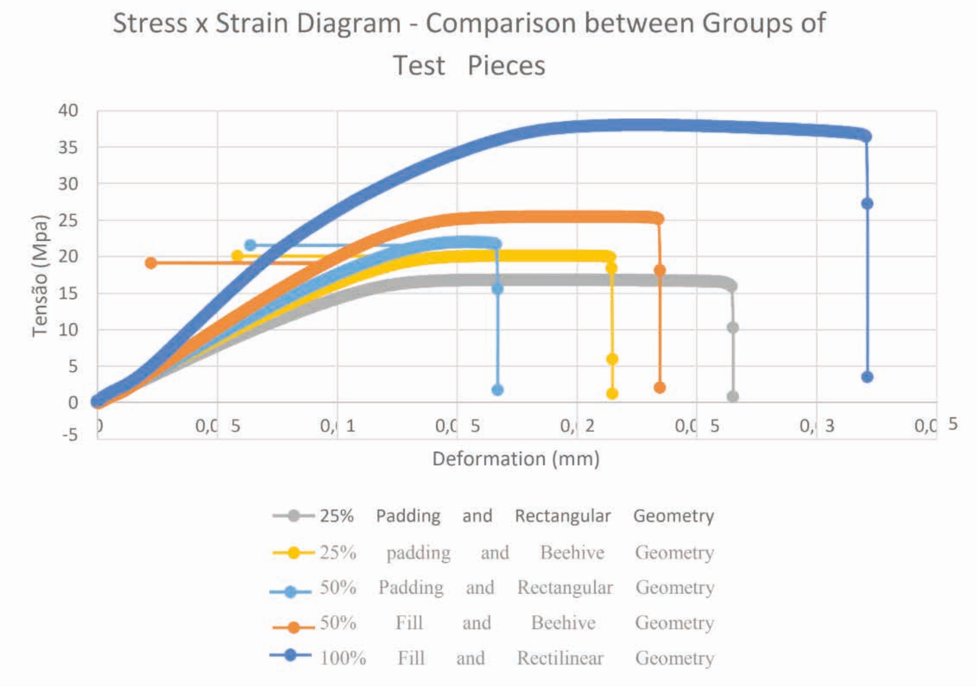
Source: Authors.

Although stretching did not vary greatly from one group to another, resistance limits showed considerable values. According to 3DLAB (2018), the honeycomb printing geometry has greater resistance than the rectangular geometry and it was possible to prove that the statement is correct, because for the same filling percentage, the honeycomb geometry showed greater resistance.

It has also been proven that the greater the filling percentage, the greater the resistance limit. The expected resistance value of 2150kN for the PLA wire (3DLAB, 2018) differs from the values of the printed structures, so this variation must be considered for the design of this structure.

Test specimen 1 had its result considered inconclusive, due to adjustments to the equipment, which had its surface layers undone due to poor adhesion of the gripper to the specimen. After the adjustments, it was possible to consider the values obtained in the other tested samples.

With the data obtained in the test, it was possible to generate a stress-strain diagram, as shown in Graph 01, demonstrating the relationship between the specimens of different groups.



Graph 01– Stress x Strain Diagram.

Source: Authors

According to Graph 01, it is possible to analyze that the TR2 group (50% filling and rectangular geometry) had a more fragile behavior, since it broke with a smaller deformation than the other groups. The TRC1 group (100% filling and rectilinear geometry) presented greater ductility in relation to the others due to the area under the curve being larger in comparison with the other groups, in addition to presenting greater deformation.

CONCLUSION

It is concluded that it is possible to establish a relationship between percentage and filling geometry and the resistance limit of a printed structure. With the values presented in the test of this work, it is possible to size a piece that must be printed in the best way, optimizing it in relation to the amount of material used and the time that can be reduced in production, aiming from the domestic use of these printers to scale industrial.

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