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ANALYSIS OF THE IMPACT OF THE PART AIR COOLING ON THE INTERLAYER YIELD STRENGTH IN ADDITIVE MANUFACTURING OF PLA AND PETG

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Abstract. *With the increasingly widespread use of additive manufacturing, it is essential to have a full understanding of the final mechanical properties of the manufactured parts in order to obtain the full advantages of this technology. From prototypes to functional parts, we are experiencing a shift of the production style, the popular called "3D Printer" is taking over industries and changing long-lasting concepts. Additive manufacturing offers a big advantage to segments like aviation, where projects last for decades and the weight of a part directly influences the performance of the plane. The possibility to produce organic shapes with ease and to maintain zero stock police, keeping the files and the 3D Printer ready to produce a part on demand, is extremely attractive to this segment. One of the key components present in practically all 3D printers, that work with material extrusion technologies by material fusion, is the cooling fan, which helps to ensure dimensional accuracy as well as improving the finish aspect of the part, but it may end up impacting the mechanical properties of the final part. The study was carried out by making specimens, according to ASTM D638, in PLA and PETG and changing the cooling fan rate for each specimen. With the performance of tensile strength tests, the difference in the yield strength was determined and the cooling fan speed was correlated with the yield limit. Finally, it was tested whether the behavior is repeated when utilizing materials from another manufacturer. The impact in the yield strength in the bond between layers suffered a reduction around 40%, when compared to printed specimens with the cooling fan turned off. This finding shows that for parts manufactured in order to resist stresses, the best practice is to use the cooling fan turned off during printing.*

Keywords: *Additive Manufacture, interlayer adhesion, process parameters, yield strength, 3D printing*

1. INTRODUCTION

Additive manufacturing systems, popularly called 3D printers, are being adopted more and more in the industry, from the manufacturing of prototypes to the production of functional parts. According to Beyerlein and Aboushama (2020), the most widespread additive manufacturing system currently used is the FFF or Fused Filament Fabrication, popularly known as personal 3D printers, which use a polymer roll in the form of a wire, extruded by a gear system to a heated nozzle that melts the material into the shape of the desired piece. The popularity is due to the low cost of the machines, low production cost materials and wide range of different materials available to use.

As demonstrated by Walsh (2017), the success and quality of a 3D printed part are extremely dependent on parameters like print speed, layer height, extruder temperature, layer width and cooling fan rotation speed, that are defined by the operator. Variations in temperature from 190 ºC to 220 ºC caused an increase of 8.2% in the tensile strength of the PLA and the increase in printing speed from 30 mm/s to 90 mm/s resulted in a 3.5% reduction in tensile strength.

According to Macedo et al. (2019), the perpendicular lines deposited on the same layer by the 3D printer act as movement restrictions for the thermal expansion and contraction of each other. Thus, the thermal residual stresses are not zero. It is possible to conclude that even though all parts of the final print suffer the same thermal variation, there is a final residual stress.

In addition to the residual thermal stress, the temperature impacts the void spaces generated between printed filaments. According to Sun et al. (2008), in the initial layers of the print, the temperature of the piece is higher and, consequently, it ends up staying longer in the glass transition range, resulting in a smaller volume of voids space than in the upper layers.

According to Bellehumeur et al. (2004), the longer the material remains above the glass transition temperature, the smaller the volume of resulting void spaces will be. Finally, the greater the empty volume, the lower the mechanical resistance of the final part, since there will be a smaller area to distribute the loads applied on the part.

For Macedo et al. (2019), it is essential to choose the appropriate printing parameters to minimize the effects of empty spaces. It is also important to remember that the smaller the percentage of empty spaces, the greater the mass of the final piece.

Therefore, this work presents an experimental study to verify the influence of forced cooling on the adhesion between layers, on the tensile strength and on the maximum elongation of specimens made of PETG and PLA.

2. METHODOLOGY

2.1 Materials

PLA or polylactic acid is a biodegradable thermoplastic produced from renewable sources that contain sugars such as corn, cassava, sugar cane etc. Its properties generally range from a glass transition temperature of 50 to 80 °C, a melting point of 170 to 180 °C and a modulus of elasticity of 2.7 to 16 GPa. PLA has some characteristics that make it the most used material by 3D printers, like the possibility of printing on non-enclosed 3D printers, not a very high glass transition temperature and low melting point, high variety of alloys and colors, results in a good surface finish, does not generate stringing, which are the residual webs when the heated nozzle travels from one point to another with the extruder turned off.

From an environmental point of view, PLA can undergo mechanical or chemical recycling processes, and be converted into virgin raw material again, without loss of properties. In addition to these options, PLA is a biodegradable thermoplastic, its degradation takes around six months to two years, and when properly disposed of, it turns into harmless substances (Andrade et al., 2016; Nampoothiri et al., 2010; Piemonte et al., 2013).

PETG is manufactured in the same way as PET, being a petroleum derivative with the addition of glycol. The addition of glycol occurs to avoid the problem that PET has with overheating, where it ends up becoming cloudy and embrittled. Other properties also undergo changes, such as a reduction in the melting temperature, an increase in flexibility and an increase in impact strength, when compared to PET. Its properties generally range from a glass transition temperature of 80 °C, a melting point of 220 to 260 °C and a modulus of elasticity of 1.5 to 2.5 GPa. Compared to PLA, PETG has some interesting advantages, such as greater flexibility and a higher glass transition temperature. However, it has a major disadvantage, it tends to generate a lot of stringing in the final piece.

The recycling of PETG is like that of PET, with the exception that it is not recommended for fiber manufacturing. Unlike PLA, it is not biodegradable and can last up to 800 years in nature when discarded. (Dupaix and Boyce, 2005; Franciszczak et al., 2018; Lacroix et al., 1996)

The filaments used were purchased from Slim 3D and 3D Fila manufacturers. Table 1 shows the mechanical properties provided by the material manufacturers, which were used as a reference value for comparison.

Table 1. Mechanical properties provided by the material manufacturers

Manufacturer	Rupture Strength (MPa)	Elongation (%)
3D Fila PETG	28	130
3D Fila PLA Basic	26.5	56
Slim 3D PLA Standard	55~65	3-5

2.2 3D Printer

The 3D printer that was used to manufacture the prototypes involved in this work is a CR-10S, from Creality, which can be seen in Figure 1. The printer's control board was replaced by a Big Tree Tech 32-bit SKR 1.4 Turbo and stepper motor control drivers were replaced by the TMC 2209. The firmware was also changed, using a customized version of Marlin 2.0. In addition to these changes, two stabilizer bars were added for the z-axis, in order to reduce vibrations, and the filament feed tube was replaced by a low-friction Capricorn tube.

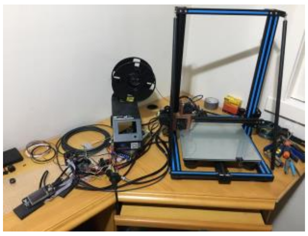

Figure 1. 3D printer used in this work.

2.3 Test specimen and srinting parameters

The ASTM D638 (2014) standard was used as the basis for the tests. The specimen used is Type I, as the materials and the thickness of the specimen meet the established criteria.

The thickness of the Type I specimen must be less than 7 mm, and it is recommended to use 3.2 mm thickness. To determine if it would be possible to perform vertical printing with such a thin thickness, 3 attempts were made to print the model using PETG, as it is the most flexible material that will be used. In the first attempt there was a failure due to detachment from the printing bed in the final part of the piece. The printing of the second occurred without any failure and in the third, when reaching the final part of the part, the specimen began to flex with the movement of the nozzle, to the point where it could no longer print the part.

Considering a 33% success rate for printing the specimens vertically and taking around 4 hours to finish, it would be unfeasible to proceed using a thickness of 3.2 mm. The specimen was remodeled to the new thickness of 6 mm, which is still less than the maximum stipulated by the standard for Type I specimens (7 mm). Print tests were redone, and the results were satisfactory, as no model was discarded due to printing failures.

The printing parameters used were determined from tests carried out with each material. First, a cube with the parameters recommended by the manufacturers of each material was printed and then, the ideal printing temperature for each material was determined by printing a temperature tower, which is a part that is configured to change the printing temperature in specified heights during the print, that allows evaluating how the material and the printer will behave in overhangs, brides and stringing for different temperatures. The ideal temperature for PETG was around 250°C, as it was the region with the lowest generation of stringing. For PLA, the ideal temperature was around 210°C, which resulted in the best finishing of the overhangs and less stringing.

Finally, in order to obtain the most solid possible filling of the part, it was adopted the strategy of using a total number of base layers greater than the maximum number of layers of the part. The specimen, with a layer height of 0.2 mm and being printed vertically, has a total of 825 layers. It was programmed a total of 999 base layers, with 0 top layers. If the default of 4 base layers and 4 top layers were kept, even with the fill set to 100%, the result of the final piece would not be a solid object. Figure 2 shows the difference between using a total number of base layers greater than the maximum number of layers (a) and 100% infill (b). So, all the prints were made entirely as "base layers", resulting in a completely solid final part. As a result, none of the parameters of infill (%, pattern and fill angle) were utilized to make the specimens. The decision to utilize only base was made to obtain a solid part, because even using a 100% infill rate, as show in Figure 2b, the final part would still have a lot of gaps between the infill lines.

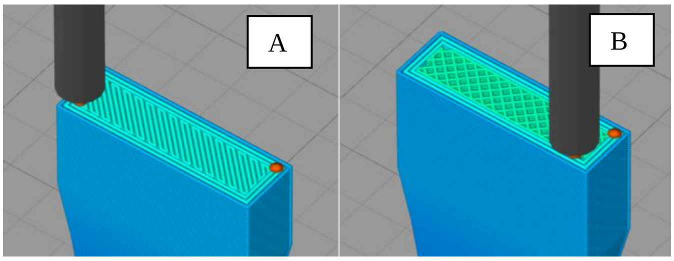

Figure 2. Difference between using only base layers (a) and 100% infill (b).

Thus, the parameters that were used in the impressions of the specimens can be seen in Table 2.

Table 2. Printing parameters used in this study.

Parameter	**PETG - 3D Fila**	**PLA - 3D Fila e Slim 3D**
Nozzle	Brass 0.4mm	Brass 0.4mm
Layer Height (mm)	0.2	0.2
Extrusion Width (mm)	0.4	0.4
Solid Base Layers	999	999
Solid Top Layers	0	0
Walls	3	3
Infill (%)	Solid	Solid
Internal Infill Pattern	-	-
Retraction Distance (mm)	9	9
Retraction Speed (mm/s)	75	75
Extruder Temperature (ºC)	250	210
Heated Bed Temperature (ºC)	70	60
Cooling	From 0% to 100%	From 0% to 100%
Printing Speed (mm/s)	60	60
Outline Wall Speed (mm/s)	30	30

The slicer software utilized in this studied was Simply 3D and all the specimens were printed individually one after another. To ensure that the vertical print would not overheat during printing, due to the small print sections, a minimum layer printing time of 15 seconds was determined in the slicer, that overwrites and reduces the speed to ensure the minimum layer printing time. No supports were utilized to make the specimens.

3. RESULTS

3.1 Yeld strength results and elongation from PLA 3D Fila

The central region of the pieces was marked to perform the elongation measurement, as well as the measurements of width and thickness of the region where the rupture occurred.

Some specimens suffered a rupture outside the desired region, as shown in Figure 3. These specimens were rejected from the analysis.

Figure 3. Specimen where breakage occurred outside the desired region.

In Table 3 are the yield and rupture strength values obtained during the tensile tests for the vertically printed specimens, and in Table 4 are the results for the horizontally printed specimens. The yield and rupture strength values obtained were identical in all the tests.

Table 3. Tensile tests result for PLA 3D Fila printed vertically.

	Yield and Rupture Strength (MPa)				
Cooling fan Speed (%)	**0**	**10**	**25**	**50**	**100**
CP 1	39.7	35.4	28.53	25	24.17
CP 2	39.4	36.1	28.79	25.7	25.3
CP 3	39.9	35.7	29.62	26.5	-
CP 4	39.8	36.97	29.2	24.7	24.3
CP 5	39.5	37	30.6	-	26
Average	39.66	36.234	29.348	25.475	24.943
Standard Dev.	±0.207364	±0.729232	±0.813001	±0. 8016	±0. 8671

Table 4. Tensile tests result for PLA 3D Fila printed horizontally.

	Yield and Rupture Strength (MPa)	
Cooling fan Speed (%)	**0**	**100**
CP 1	45.9	42.2
CP 2	45.2	41.9
CP 3	44.7	40.7
CP 4	44.7	41.4
CP 5	45.9	40.9
Average	45.28	41.42
Standard Dev.	±0.601664	±0.637966

Comparing these results with the values provided by the manufacturer, which can be seen in Table 1, the values obtained are similar to the results of tests carried out with the cooling fan turned on above 50%. Considering that one of the manufacturer's recommendations is forced cooling at 100% from the second layer, it is possible to assume that this parameter was used, being consistent with the values obtained in the test. Analyzing the scenario with the cooling fan turned off, or in horizontal prints, the values obtained were higher than those provided by the manufacturer.

In Figure 4 and Figure 5 are shown the graphs generated with the relationship between the cooling fan speed and the yield strength values. In Figure 4, we have the graph for vertically printed materials, and it is possible to see that the cooling fan turned on drastically affects the adhesion force between the layers, resulting in a decrease of up to 40% in the yield and rupture strength in the region with the speed of the cooling fan between 0% and 40%.

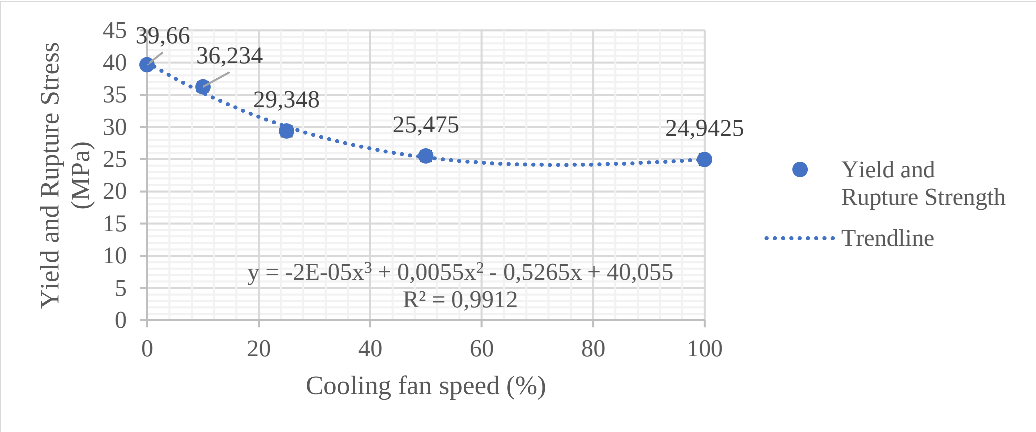

Figure 4. Yield and Rupture Strength *vs* cooling fan speed for PLA 3D Fila manufactured vertically.

It can be seen in Figure 5 the graphic relating to specimens that have been printed horizontally, where the forced cooling had no significant impact, suffering a reduction of approximately 8.5% in yield and rupture strength between the cooling fan turned off and at maximum speed.

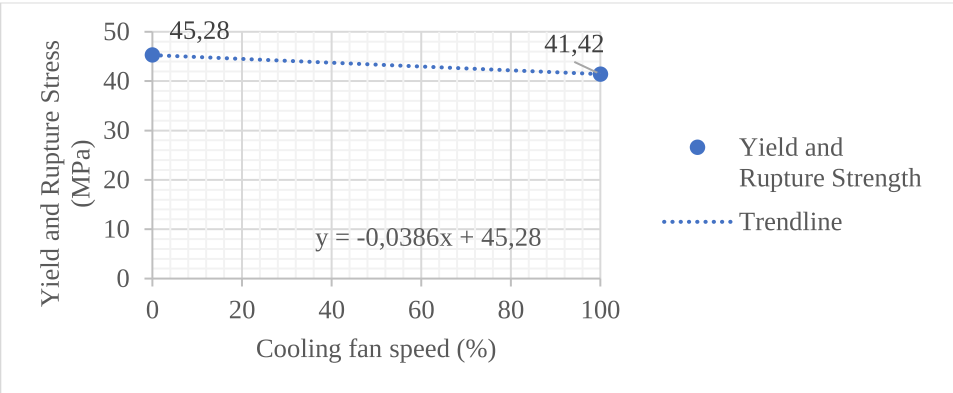

Figure 5. Yield and Rupture Strength vs cooling fan speed for PLA 3D Fila manufactured horizontally.

Comparing the results obtained between parts manufactured horizontally vs vertically, with the cooling fan turned off, parts manufactured horizontally have a yield and rupture strength approximately 12% higher than those manufactured vertically. When the cooling fan is at 100%, the parts manufactured horizontally have a yield and rupture strength about 40% higher than those manufactured horizontally.

In addition to the difference in yield stress strength, there were no differences in the maximum elongation of the specimens. All those manufactured vertically broke in the regions between the layers. For the specimens manufactured horizontally, there were also no differences in the maximum elongation, as shown in Figure 6.

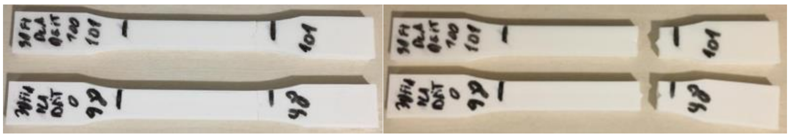

Figure 6. Resulting elongation on specimens manufactured horizontally.

3.2 Yeld strength results and elongation from PLA Slim 3D

The central region of the pieces was marked to perform the elongation measurement, as well as the measurements of width and thickness of the region where the rupture occurred.

In all, there were 3 breaks outside the determined region, one for the specimens manufactured with the cooling fan at 0%, another for the cooling fan at 10% and the last one with the cooling fan at 50%. These three results were excluded from the analyzed data. In Table 5 are the yield and rupture strength values obtained during the tensile tests for the vertically printed specimens. There were no differences between the yield and rupture strengths.

In Table 6 are the yield and rupture strength results for the horizontally printed specimens. There was a small variation in the rupture strength for the specimens manufactured with the cooling fan turned off, where a plastic deformation zone began to occur and then failure occurred. For tests manufactured with the cooling fan turned on at maximum, the rupture strength was equal to the yield strength.

Table 5. Tensile tests result for PLA Slim 3D printed vertically.

	Yield and Rupture Strength (MPa)				
Cooling fan Speed (%)	**0**	**10**	**25**	**50**	**100**
CP 1	-	35	22.5	21	20.7
CP 2	36.4	28.1	22.1	-	20.3
CP 3	37.8	31.5	23.2	21.8	18.7
CP 4	36.3	-	22.4	21.9	21.2
CP 5	38.9	31.6	23.1	22.5	21.2
Average	37.35	31.55	22.66	21.8	20.42
Standard Dev.	±1.2396	±2.8172	±0.4722	±0.6164	±1.033

Table 6. Tensile tests result for PLA Slim 3D printed horizontally.

	Yield Strength (MPa)		Rupture Strength (MPa)	
Cooling fan Speed (%)	**0**	**100**	**0**	**100**
CP 1	51.9	44.9	51.9	44.9
CP 2	48.8	45.9	46.6	45.9
CP 3	47	44.4	42	44.4
CP 4	48.6	44.1	45.8	44.1
CP 5	48.9	45.9	44.5	45.9
Average	49.04	45.04	46.16	45.04
Standard Dev.	±1.7757	±0.8355	±3.65	±0.84

The rupture strength provided by the manufacturer, which can be seen in Table 1, is quite different from the value obtained in the tests. One of the reasons for this difference may be the base standard used for the tests. The manufacturer followed the ISO 527 standard. Therefore, these values cannot be compared with the results obtained in the tests performed.

In Figure 7 and Figure 8 are shown the graphs generated with the relationship between the cooling fan speed and the yield strength values. The graph for vertically printed materials, Figure 7, shows that the cooling fan turned on drastically affects the adhesion force between the layers, resulting in a decrease of up to 40% in yield strength in the region with cooling fan speed between 0% and 25 %. The yield and rupture strength drop practically linearly in this region, until it stabilizes for cooling fan speeds between 25% and 100%.

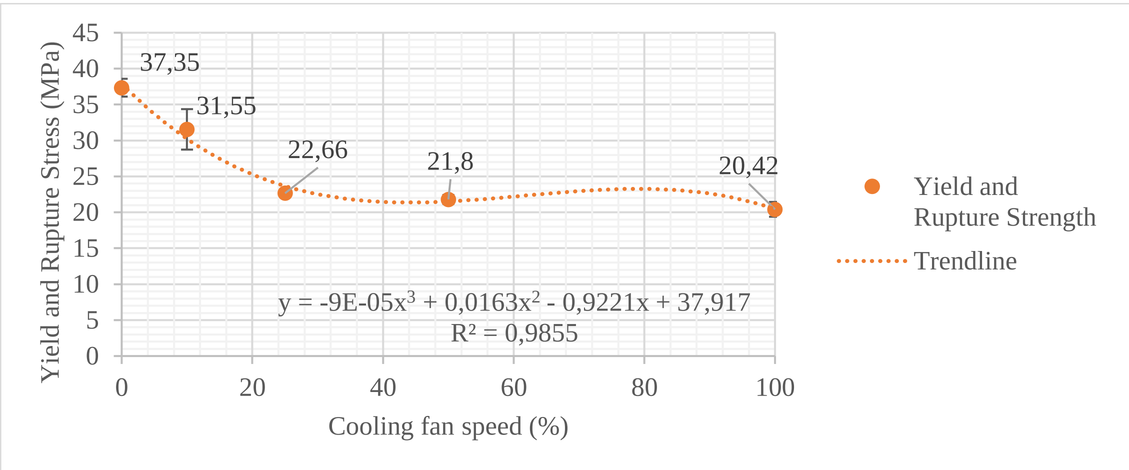

Figure 7. Yield and Rupture Strength vs cooling fan speed for PLA Slim 3D manufactured vertically.

It can be seen in Figure 8 the graphic relating to specimens that have been printed horizontally, where the forced cooling had no significant impact, suffering a reduction of approximately 8.2% in yield strength and of 2.5% in rupture strength between the cooling fan turned off and at maximum speed.

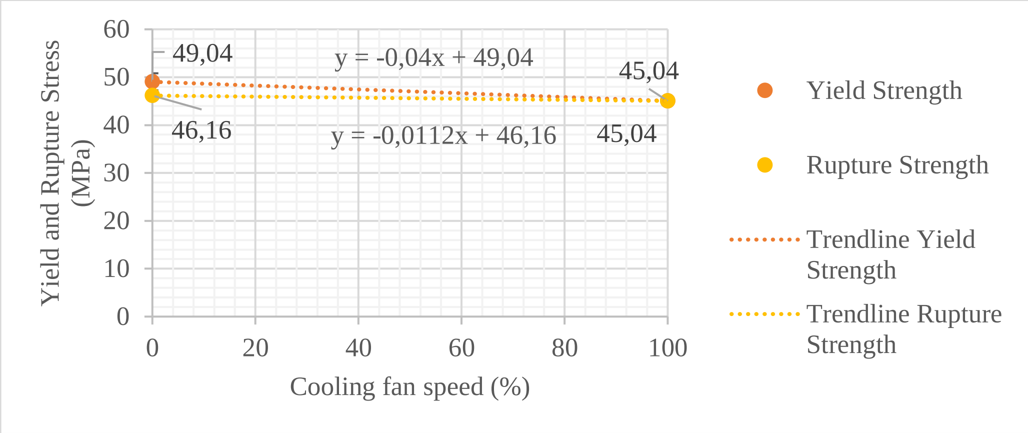

Figure 8. Yield and Rupture Strength vs cooling fan speed for PLA Slim 3D manufactured horizontally.

Comparing the results obtained between parts manufactured horizontally vs vertically, with the cooling fan turned off, parts manufactured horizontally have a yield and rupture strength approximately 24% higher than those manufactured vertically. When the cooling fan is at 100%, the parts manufactured horizontally have a yield and rupture strength about 55% higher than those manufactured horizontally.

In addition to the difference in yield stress strength, there were no differences in the maximum elongation of the specimens. All those manufactured vertically broke in the regions between the layers. For the specimens manufactured horizontally, there were also no differences in the maximum elongation, as shown in Figure 9.

Figure 9. Resulting elongation on specimens manufactured horizontally.

3.3 Yeld strength results and elongation from PETG 3D Fila

The central region of the pieces was marked to perform the elongation measurement, as well as the measurements of width and thickness of the region where the rupture occurred. In all, there were 4 breaks outside the determined region, two for the specimens manufactured with the cooling fan at 10%, one for the cooling fan at 50% and the last one with the cooling fan at 100%. These four results were excluded from the analyzed data. In are the yield strength values obtained during the tensile tests for the vertically printed specimens and in are the results for the horizontally printed specimens.

In Table 7 are the yield and rupture strength values obtained during the tensile tests for the vertically printed specimens. There were no differences between the yield and rupture strengths.

In Table 8 are the yield and rupture strength results for the horizontally printed specimens. There was a great variation in the rupture strength for the specimens manufactured with the cooling fan turned off, where most of the specimens tested did not suffer rupture, and the test was interrupted by the test machine distance limits. For tests manufactured with the cooling fan turned on at maximum, the rupture strength was also well below the yield strength, but rupture occurred in all tested specimens.

Table 7. Tensile tests result for PETG from 3D Fila printed vertically.

	Yield and Rupture Strength (MPa)				
Cooling fan Speed (%)	**0**	**10**	**25**	**50**	**100**
CP 1	29.3	28	25.2	22.3	19.3
CP 2	31.5	29.5	24.1	-	20.8
CP 3	32.7	-	26.6	22.5	18.4
CP 4	35	-	24.5	21.6	21.5
CP 5	34.5	27.9	27.8	22.7	-
Average	32.6	28.467	25.64	22.275	20
Standard Dev.	±2.3173	±0.8963	±1.5372	±0.4787	±1.4071

Table 8. Tensile tests result for PETG from 3D Fila printed horizontally.

	Yield Strength (MPa)		Rupture Strength (MPa)	
Cooling fan Speed (%)	**0**	**100**	**0**	**100**
CP 1	47.2	43.2	4.8	33.5
CP 2	48.2	42	-	35.1
CP 3	48.7	41.6	-	26.4
CP 4	47.3	41.4	4.9	28.23
CP 5	47.8	41.4	-	32
Average	47.84	41.92	4.85	31.05
Standard Dev.	±0.6269	±0.7563	0.07	3.64

Comparing these results with the values provided by the manufacturer, which can be seen in Table 1, the results are similar with the tests performed with the cooling fan at 10%. Analyzing the scenario with the cooling fan turned off, or in horizontal prints, the values obtained were higher than those provided by the manufacturer. In Figure 10 and Figure 11 are shown the graphs generated with the relationship between the cooling fan speed and the yield and rupture strength values. The graph for vertically printed materials, Figure 10, shows that the cooling fan turned on drastically affects the adhesion force between the layers, resulting in a decrease of up to 33% in yield and rupture strength in the region with cooling fan speed between 0% and 50 %. The behavior of the mean yield strength was within a pattern predicted by the mean trendline equation.

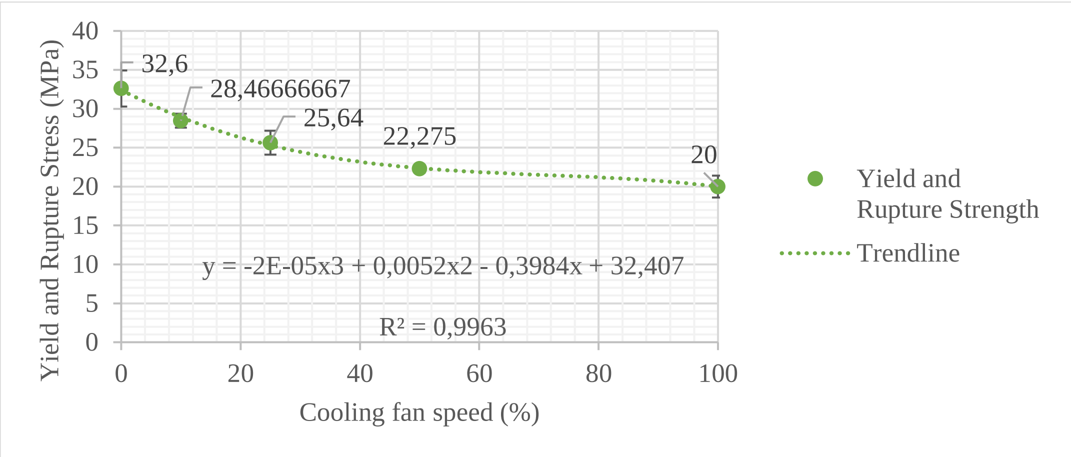

Figure 10. Yield and Rupture Strength vs cooling fan speed for PETG 3D Fila manufactured vertically.

It can be seen in Figure 11 the graphic relating to specimens that have been printed horizontally, where the forced cooling had a greater impact on the yield strength, suffering a reduction of approximately 13% in yield strength between the cooling fan turned off and at maximum speed. In the rupture strength, most of the specimens manufactured with the cooling fan turned off did not even break, with the test stopping by the test machine distance limits. And for specimens manufactured with the cooling fan turned on at 100%, the values of rupture strength were 26% below their yield strength.

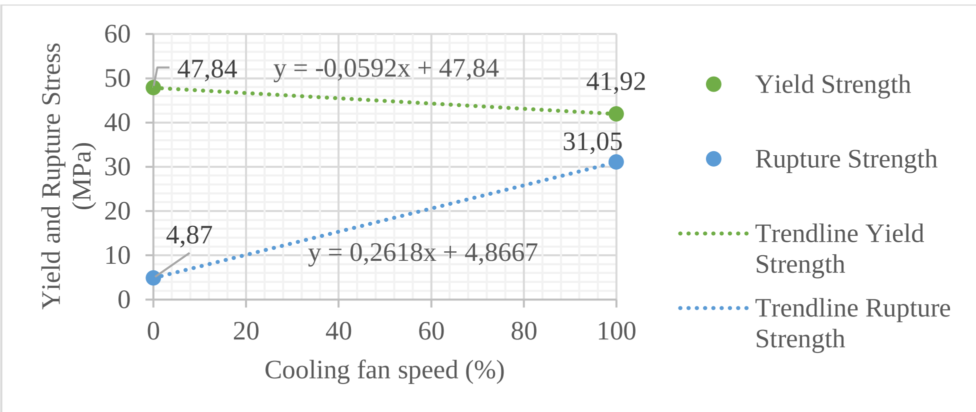

Figure 11. Yield and Rupture Strength vs cooling fan speed for PETG 3D Fila manufactured horizontally.

Comparing the results obtained between parts manufactured horizontally vs vertically, with the cooling fan turned off, parts manufactured horizontally have a yield strength approximately 32% higher than those manufactured vertically. When the cooling fan is at 100%, the parts manufactured horizontally have a yield strength about 52% higher than those manufactured vertically.

In addition to the difference in yield strength, there were no differences in the maximum elongation for the specimens that were manufactured vertically, they broke in the regions between the layers. As for the specimens manufactured horizontally, there were significant differences in the maximum elongation, as shown in Figure 12.

Figure 12. Resulting elongation on specimens manufactured horizontally.

Comparing the yield strength with the displacement resulting from the test, the result is even more expressive. Figure 13 shows the common result for all tests performed for PETG with the cooling fan at 100% speed on parts manufactured horizontally, where occurred a small region of plastic deformation and then the total failure and rupture of the specimen. In Figure 14, it is possible to see the results for all the tests performed for PETG with 0% cooling fan speed on parts manufactured horizontally, where none of the test specimens tested was broken. Comparing these results with the classic stress-strain curve for a semi-crystalline polymer, from sources like Callister e Rethwisch (2008), it follows the same pattern of deformation and formation of the "neck", thus behaving as a solid specimen and not 3D printed.

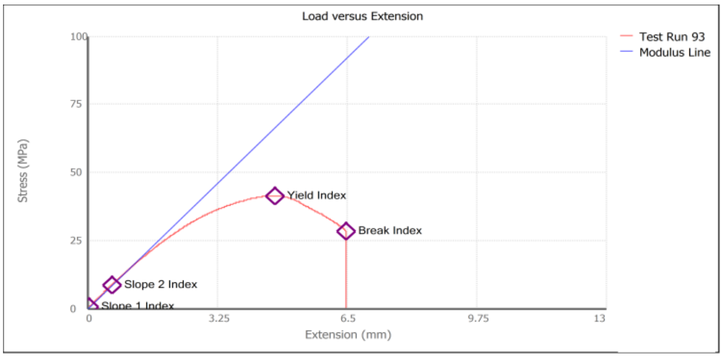

Figure 13. Stress *vs* displacement for PETG with cooling fan at 100%.

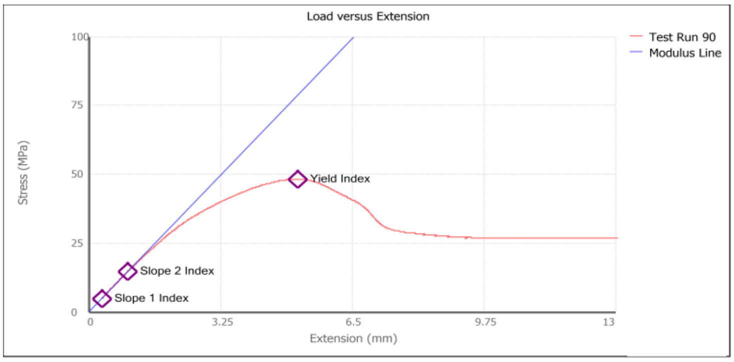

Figure 14. Stress *vs* displacement for PETG with cooling fan at 0%.

It can be seen that parts manufactured with the cooling fan turned off behave in accordance with the classic stress-strain diagram for semi-crystalline polymeric materials, with the formation of a "neck" after the flow stress region and undergoing constant elongation, without suffering a rupture. The parts manufactured with the cooling fan at full speed, on the other hand, did not form the "neck" and broke soon after reaching the yield strength value.

4. CONCLUSION

The growing use of additive manufacturing justifies the search for understanding the behavior of parts manufactured with this technology. In this work, we sought to characterize the behavior of different polymeric materials, PETG and PLA, varying the speed of the extruder cooling fan, thus allowing for a better understanding of its impact on parts.

The study was carried out using specimens manufactured in accordance with ASTM D638 and using cooling fan rotation speeds of 0%, 10%, 25%, 50% and 100% for specimens manufactured vertically and the speeds of 0% and 100% for those manufactured horizontally.

Tensile tests were carried out and from the results obtained, it can be observed that in all tests, for PETG and PLA, the maximum yield strength was obtained for the specimens manufactured with the cooling fan turned off. It was analyzed PLA from two different manufacturers, which showed similar results and a decrease in yield strength. There was around 40% reduction between the cooling fan turned off and turned on at maximum speed for the parts manufactured vertically and close to 9% for the parts manufactured horizontally. It was not possible to notice a difference in the elongation between the tests, as they all broke up during the tests.

For PETG, the yield strength reduction was approximately 33% between the cooling fan turned off and turned on at full speed for parts manufactured vertically and around 13% for parts manufactured horizontally. For the parts manufactured vertically, it was not possible to notice a difference in elongation, as they all broke in the adhesion lines between the layers, unlike the horizontal ones, which presented significant elongation variation, even behaving in accordance with the classic stress-strain diagram for semi-crystalline polymeric materials.

It was also seen that the difference between the yield strength for specimens made horizontally and vertically were drastically different and strongly impacted by the cooling fan. With the cooling fan turned off, the difference between the horizontal and vertical direction was between 12% and 32% of the yield strength, with the horizontal direction being the most resistant. With the cooling fan at 100%, the difference between the horizontal and vertical direction was between 40% and 55% of the yield strength, with the horizontal direction being the most resistant. This shows that to achieve better mechanical properties of the part it is necessary to consider the printing direction, leaving the print layers perpendicular to the forces applied to the part.

Turning off the cooling fan will provide better mechanical strength, and even allow for greater stretch under tension in the case of PETG. To print with the cooling fan turned off, it is recommended to design the part without overhangs and with larger gaps. The yield strength drop curve was different for PLA from different manufacturers and for PETG, but the maximum percentage reduction rate of stress values was similar.

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