Article

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Destructive Test in 3D Printing

Ensayo Destructivo en Impresión 3D

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Abstract

Today it is essential for any manufacturing company, to be able to have information about the effectiveness of the designs, as well as the quality of its raw materials, due to this, one of the key strategies is the prototyping of parts through additive manufacturing, the objective of this article is to provide information about the structural resistance of a 3D printed component through the effectiveness in the deposition of extruded filament and according to a deposition made, the implicit variables for both cases will be determined, which will be measured by tests. destructive, identifying values of deformation versus effort and will contribute to the determination of advantages and disadvantages of the impression, as well as the position with which the deposition is made.

Printing, Resistance, Test

Resumen

Hoy en día es imprescindible para cualquier empresa manufacturera, el poder tener información acerca de la efectividad de los diseños, así como de la calidad de sus materias primas, debido a ello una de las estrategias clave es el prototipado de partes mediante manufactura aditiva, el objetivo de este artículo es proveer información acerca de la resistencia estructural de un componente impreso en 3D mediante la efectividad en la deposición de filamento extruido y de acuerdo a una deposición efectuada, se determinarán las variables implícitas para ambos casos, las cuáles se medirán mediante ensayos destructivos, identificando valores de deformación versus esfuerzo y se contribuirá en la determinación de ventajas y desventajas de la impresión, así como la posición con la se realiza la deposición.

Impresión, Resistencia, Ensayo

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Introduction

3D printing is an additive manufacturing method, with which prototype models or functional work components can be generated, this method involves the application of material input, which can be of different properties and characteristics, among the most used:

– PLA
– ABS
– Resin
– Metallic powders.

This technique is very useful for the production of parts, however, in the manufacturing process that ranges from design to preparation, it is vitally important to identify the best position of the component, which will structurally define the way in which which the filler material will be deposited and in the definition of the Cartesian trajectories in which the printing machine generates the material deposition.

In addition to the above, the way in which the position of the element to be printed is defined will depend on its geometry, since from this it will depend on the need for support, the printing time, the amount of material input and the structural resistance of the component, due to this, the present investigation will identify these change factors and through a destructive stress test, the effectiveness of the method in relation to the direction of material deposition can be measured.

The relationship of the deformation factor (dependent variable) with respect to the stress factor (independent variable) and through a plastic specimen with PLA material in a configuration directed from the design process, preparation of files according to the extension of the modeling software , preparation process for post-processing, execution of 3D printing in horizontal and vertical position and application of tests, will allow observing the result of the implicit variables in each proposal and verified by applying destructive testing.

Development of Sections and Sections of the Article with subsequent numbering

In the application of the destructive test to identify the resistance in the proposed specimens, it is important to work in the following stages, which are:

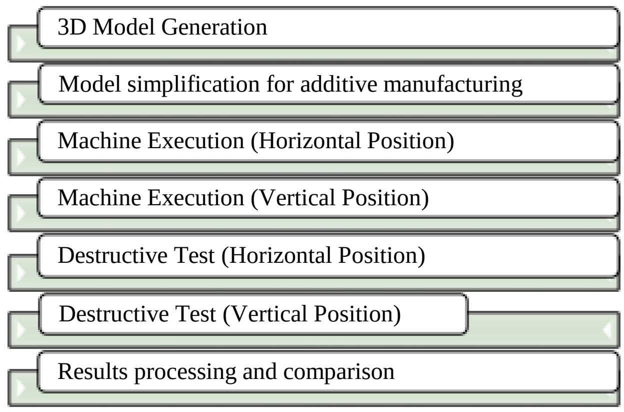

Figure 1 Stages of 3D printing and destructive testing (Boisas, 2018)

1. Design of the 3D model

The design of the 3D model, part of the GeDG (Computer extended Descriptive Geometry) structure, which is oriented to a sequence of geometric construction, this leads the generation of the model to focus on dimensional qualities in a graphical environment, which provides Cartesian positions in the generation of the element, of which axes x, y and z.

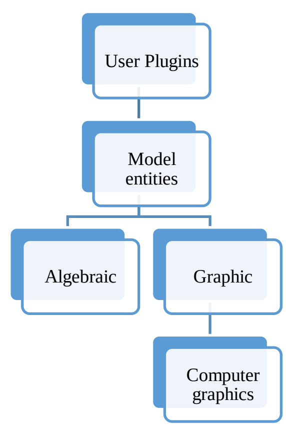

Figure 2 Modelo GeDG
(Prado-Velasco, García-Ruesgas, Ortíz-Martín 2023)

Taking the previous structure as a reference, the specimen is modeled in the CAD software environment and under the standard (ASTM D638), the three-dimensional design is generated according to the resistance of the material to be used (PLA).

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For the beginning of the design of the specimen, a round smooth head specimen is considered, with origin in Cartesian coordinates at 0.

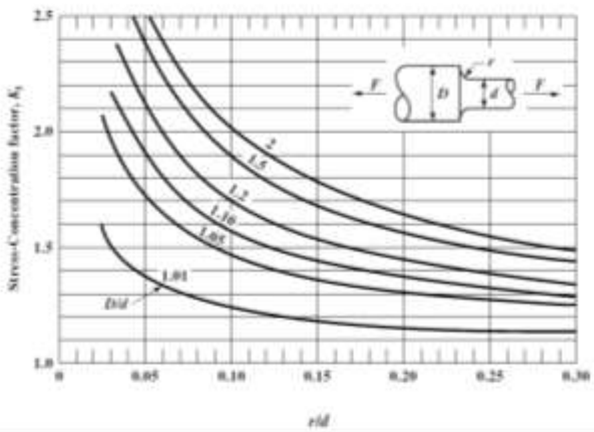


Figure 3 Factor stress-concentration
(McCauley, 2013)

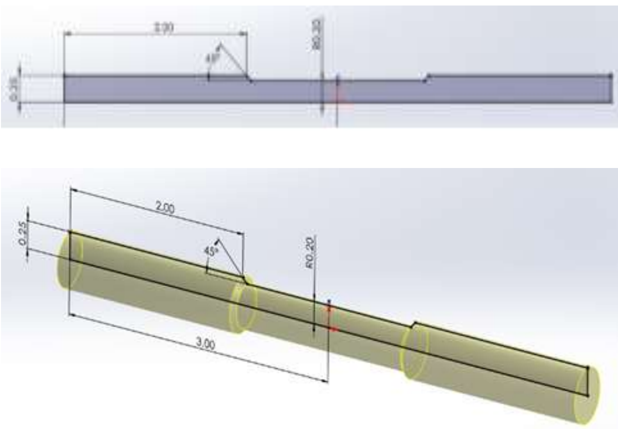
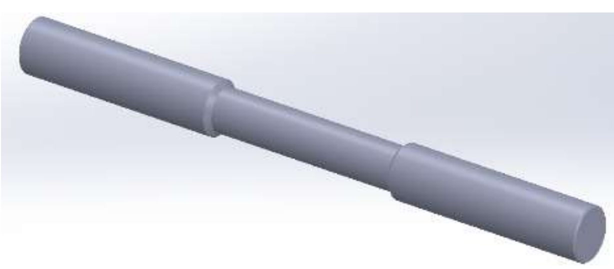


Figure 4 Zero Origin Specimen Design
(Contribution to the project, unpublished)

2. Simplification of the model for additive manufacturing

The three-dimensional model is a very important factor in the preparation process for printing, since according to the GeDG structure approach, it supposes a solid element, since in the software environment the element is floating, it must be to achieve a preparation of the modeling, this by means of a recognition of nodes from a binary element.



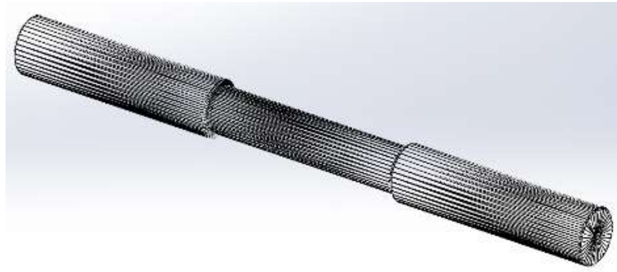


Figure 5 Design simplification
Contribution to the project, unpublished

During the model simplification process, each binary element of the model is configured to the origin in the Cartesian system, which generates a position value in space. Said value will be determined from the import of the file in post software. processed for geometric recognition, and trajectory assignment.

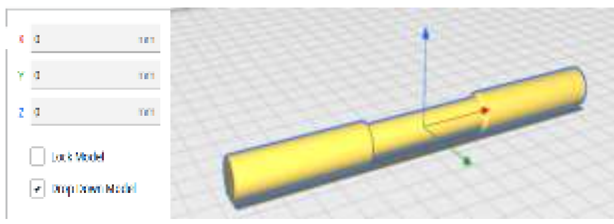


Figure 6 Geometric Recognition, horizontal position (Contribution to the project, unpublished)

After the geometric recognition stage, the positions of each binary element of the component will be identified and a translation process into standard language, better known as G Language, will be generated through which the printing process can be governed, through a sequence of codes and trajectories in a Cartesian plane with which the deposition of material will be achieved at each necessary space and corresponding to the model in three dimensions and supported with a 3D printing machine with a base extruder at temperature conditions between 180 and 200 ° c.

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;FLAVOR:Marlin ;TIME:1763 ;Filament used: 3.89792m ;Layer height: 0.3 ;MINX:117.489 ;MINY:190.45 ;MINZ:0.3 ;MAXX:282.508 ;MAXY:209.897 ;MAXZ:12.6 ;Generated with Cura_SteamEngine 5.2.2 M140 S60 M105 M190 S60 M104 S200 M105 M109 S200 M82 ;absolute extrusion mode M107 ;Start with the fan off	G92 E0 G92 E0 G1 F2400 E-6 ;LAYER_COUNT:42 ;LAYER:0 M106 S255 M204 S3000 M205 X10 Y10 G1 F600 Z0.375 G0 F3000 X120.935 Y191.511 Z0.375 M204 S1800 M205 X8 Y8 ;TYPE:SKIRT G1 F600 Z0.3 G1 F2400 E0 G1 X121.571 Y191.183 E0.04998 G1 X122.239 Y190.929 E0.0999 G1 X122.932 Y190.751 E0.14987 G1 X123.761 Y190.634 E0.20835

Table 1 Horizontal ISO language (Project contribution, unpublished)

3. Machine Execution (Horizontal Position)

During the machine execution process, there is a simulation stage, which will show the user the trajectories defined according to the binary system, which is translated into ISO language by post-processing software algorithms. It is important to mention that the Characteristics can be of a proposed nature or can be customized by the user according to the geometric characteristics.

According to Güler Özgül, H.., & Tatlı, O. (2021), considering these factors is a highly relevant issue since the difference between geometries, as well as the direction during the deposition of material, may have different mechanical properties, which will contribute to the different resistance values depending consequently on the location and load that acts on them when constituting a geometric structure

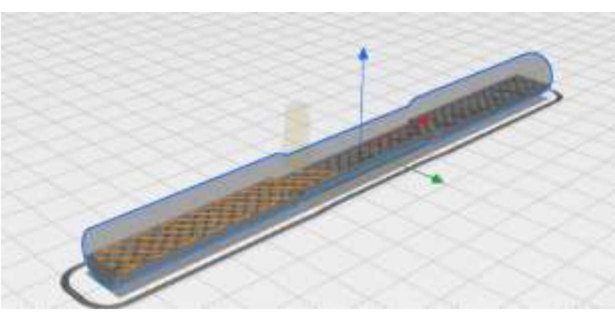

Figure 7 Preview horizontal trajectories, (Contribution to the project, unpublished)

Once it has been identified by the user that the trajectories have been recorded, it is transferred to a removable memory, in which the standard programming language (Language G) will be stored and it will be physically connected to the printing machine to start with the manufacturing process by additive manufacturing (3D printing).

The 3D printing machine must cover work parameters in order to carry out the deposition efficiently, among which:

- Extrusion temperature (200°C)
- Printing table temperature (60°C)

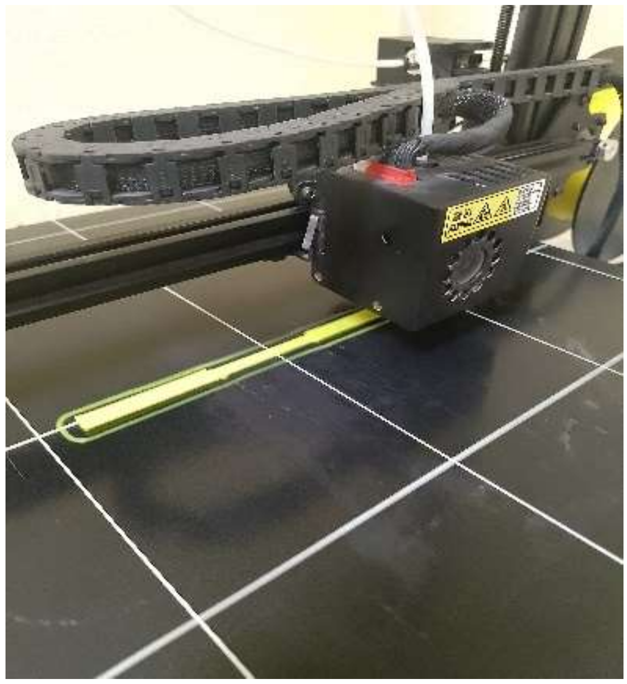

Figure 8 Landscape 3D printing
(Contribution to the project, unpublished)

4. Machine Execution (Vertical Position)

After the horizontal prints, the prints will be made in a vertical position, it should be noted that the machine parameters are the same, which were described in the previous section and the change factor for printing these tests will be the position In this process, once both samples are finished, the resistance given according to the material deposition will be identified.

It is important to highlight that during the parameter setting process, the capacity dimensions of the printer must be considered, according to its total height, since a maximum degree of opening must be avoided, at the same time that it must be avoid collision during the deposition process.

Of the extruder with respect to the test tube, since its base area is proportional to the dimension of the standardized test tube, which generates a possible detachment of the printing table at the moment of being displacing the extruder on the axes considered during the post-processing process when generating the ISO printing program.

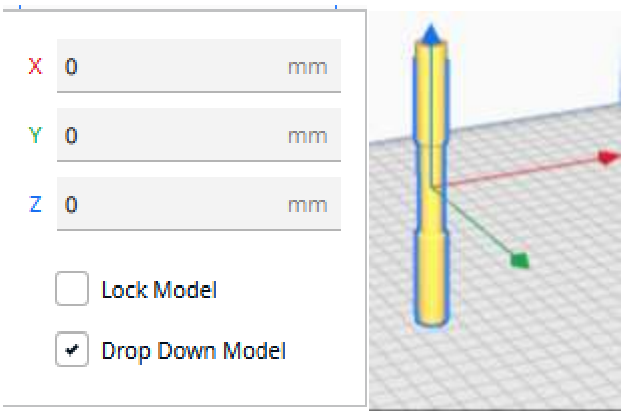

Figure 9 Geometric recognition, vertical position,
(Contribution to the project, unpublished)

;FLAVOR:Marlin ;TIME:2739 ;Filament used: 3.80996m ;Layer height: 0.3 ;MINX:186.955 ;MINY:186.953 ;MINZ:0.3 ;MAXX:213.044 ;MAXY:213.036 ;MAXZ:152.4 ;Generated with Cura_SteamEngine 5.2.2 M140 S60 M105 M190 S60 M104 S200 M105 M109 S200 M82 ;absolute extrusion mode M107 ;Start with the fan off	G92 E0 G1 F2400 E-6 ;LAYER_COUNT:508 ;LAYER:0 M106 S255 M204 S3000 M205 X10 Y10 G1 F600 Z0.375 G0 F3000 X190.606 Y190.949 Z0.375 M204 S1800 M205 X8 Y8 ;TYPE:SKIRT G1 F600 Z0.3 G1 F2400 E0 G1 X191.327 Y190.257 E0.0698 G1 X192.184 Y189.548 E0.14749 G1 X193.1 Y188.93 E0.22467 G1 X194.042 Y188.39 E0.30051 G1 X195.001 Y187.952 E0.37414 G1 X195.514 Y187.758 E0.41245

Table 2 Vertical ISO language
(Project contribution, unpublished)

In the sequence of machine execution stage 4, of the printing process in vertical position, the post-processing software adjusts to a different sequence of the trajectory in the coordinate system, said process performs the simulation of plastic deposition PLA.

In which a different process is observed in the application of the material, but the same in the geometric shape of the standardized specimen.

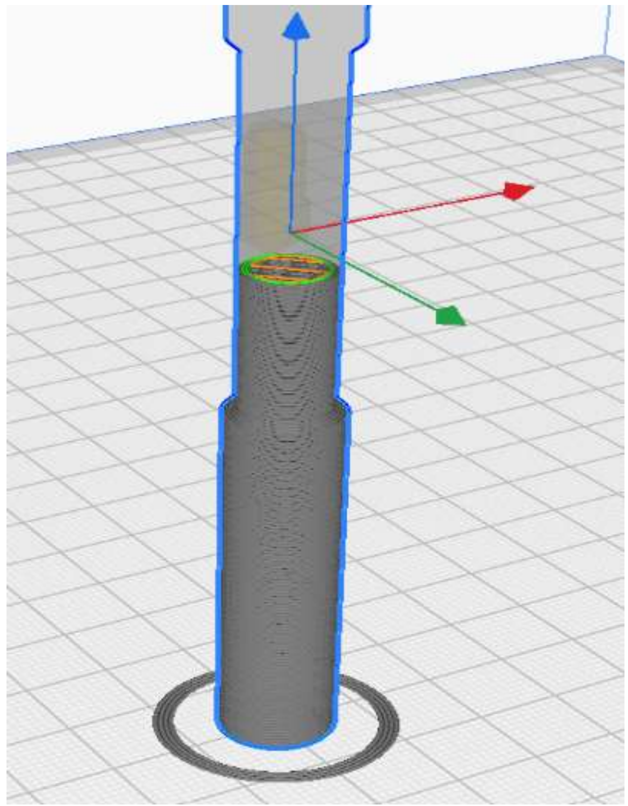

Figure 10 Preview vertical paths
(Contribution to the project, unpublished)

Once the trajectories have been simulated by the software and no interferences have been detected in the code, the standard programming language (Language G) is once again transferred to carry out the manufacturing process by additive manufacturing (3D printing), this time in a vertical position.

The work parameters must be reviewed again in order to carry out the deposition efficiently, the following will be considered again:

– Extrusion temperature (200°C)
– Printing table temperature (60°C)

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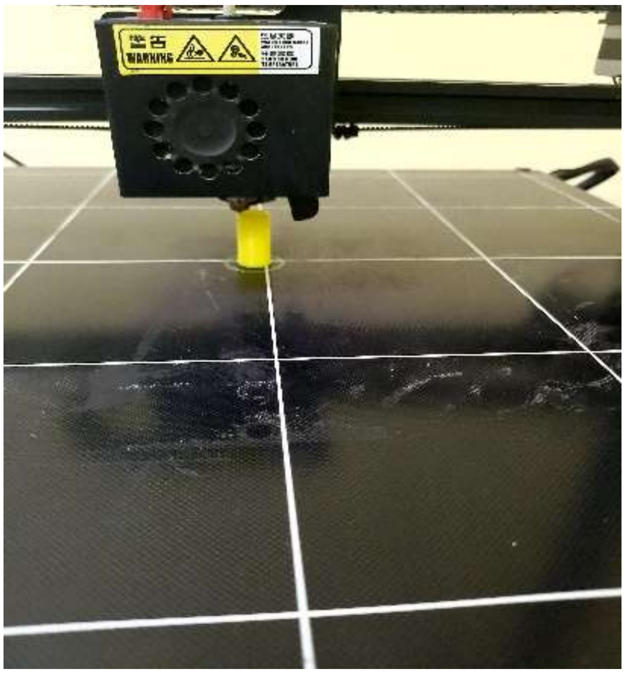

Figure 11 Vertical 3D printing
(Contribution to the project, unpublished)

5. Destructive Test (Horizontal position)

By definition, a destructive test is the verification of mechanical properties, which can be:

– Static: Hardness, traction, compression, shearing, bending, buckling, creep.

– Dynamic: Shock resistance, wear, fatigue (Moreno, López-González, Malagón-Mendoza, Henao-Vega, 2006).

For the present investigation, a tension study will be applied, this concept is based on a physical study in which a solid is subjected to the action of a system of external forces, which is recognized when there is the application of loads and consequently a reaction is obtained, which is why it is defined that any member that supports a load is deformed by the influence of the applied load according to its direction and magnitude, which will be proportional and transversal to its section area (Mott, R. L. , Salas, R.N., Flores, M.A.R., & Martínez, E.B.-2009).

The direct action of the application of loads in a solid is represented by the presence of forces in interaction through the surface, these forces achieve an interaction, they are equal in opposite directions on the contact sections (Cervera-Ruiz, Blanco-Díaz, 2002).

The relationship in this interaction process is achieved in the proportion in which the force or load acting on a surface generates a condition called effort, which is denoted by the assignment of the Greek letter sigma σ.

According to the direction in which the force is applied, two types of effort are obtained, of which:

– Compression stress, which occurs to the extent that the action of the forces is collinear, that is, in the same direction.

– Effort of tension or traction, which occurs to the extent that the action of the forces is concurrent, ie in the opposite direction.

Once the relationship to the cross-sectional area has been identified, it will be possible to identify the effects of effort and force (Guzmán, 2005).

$$\sigma = \frac{F}{A} \tag{1}$$

According to the previous theorem, a test will be considered taking into account the action of the force applied in a uniaxial manner and a section of cross-sectional area of the specimen that was printed horizontally, this to identify the effort to which it is subjected. and identify the value of the maximum force and the resulting deformation, this process will be carried out in a WAW-1000D destructive testing equipment, this machine allows the specimen to be held according to its geometry, which can be flat or with a cylindrical head,

For the present study, a change in the clamping means is considered through the jaws, since the geometry is cylindrical, for which smooth head jaws will be used, with a V-cut, which is determined to achieve effectiveness. in the process of measuring the resistance of the component, which according to the shape and dimensions of the test tube for each case, will consider the uniform cross section and its type of manufacturing process, which may include cast test tubes and test tubes with or without machining, which will be essential in the study to obtain the necessary measurement data and according to the variables that are sought to be obtained from the study CASTRILLÓN, A. A., & TORRES, M. R. M. (2017).

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Figure 12 Destructive test, horizontal specimen
(Contribution to the project, unpublished)

For the validation of the destructive test, a population sample size of 50 test tubes is being considered, of which the following will be measured:

- Upper Yield Force
- Stress
- Deformation

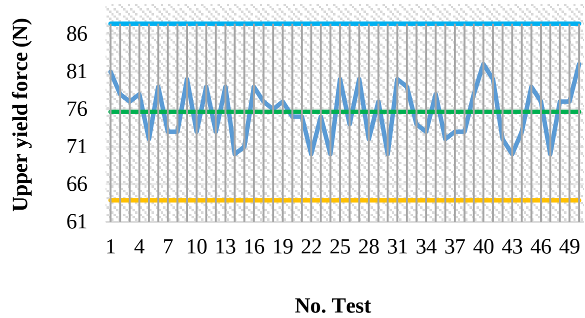
Likewise, the Average value of the sample and the limits of the test will be validated, this as a method of consideration of the consistency of the test and biases in the study.

3D printed specimens in horizontal position				
No. Test	UYF (N)	Strees (Pa)	Deformation	Test speed
1	81	1031452	0.0003126	5 N/S
2	78	993250	0.0003010	
3	77	980517	0.0002971	
4	78	993250	0.0003010	
5	72	916847	0.0002778	
6	79	1005984	0.0003048	
7	73	929581	0.0002817	
8	73	929581	0.0002817	
9	80	1018718	0.0003087	
10	73	929581	0.0002817	

Table 3 Measurement of Upper Yield Force, Horizontal Specimen (UYF)
(Contribution to the project, unpublished)

During data processing and considering the relationship between tests, it is observed that the individuals in the population have a normal discrepancy among themselves, but they remain at control values, which translates into a correct application of the test.

- MEAN: 75.64 N
- UCL: 87.42 N
- LCL: 63.86 N



Graphic 1 Control Chart UYF horizontal
(Contribution to the project, unpublished)

In the process of application of the load during the test, it can be seen that the rupture condition occurs at an average value of 75.64N, at this stage a detachment of filaments can be seen, which manage to behave as tensioned threads at a maximum load, to later generate a detachment by uniaxial action, by determination it is appreciated that fatigue is directly related to the degree of resistance that the presence of filaments opposes in the construction architecture, which according to Becerra, J. L., Díaz-Rodríguez , J. G., & González-Estrada, O. A. (2020), is obtained using a concentric and isotropic arrangement of fiber reinforcement, which interlocks the deposition groups parallel to the section set.

Figure 13 Destructive test horizontal position
(Contribution to the project, unpublished)

Due to the type of test and the 3d printing position in the manufacturing process of the specimen, an elongation is observed, which manages to be translated and calculated by means of the value of the deformation which is present in the given value of the effort and the elastic modulus (Guzmán, 2005).

$$\varepsilon = \frac{\sigma}{E} \tag{2}$$

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6. Destructive Test (Vertical Position)

In this stage of the test, the condition in the manufacture of the test tube is changed, which, as explained in stage 4, will be carried out by deposition of PLA material in a position parallel to the extrusion axis and in a vertical direction to the printing table. , which under the same criteria in the WAW-1000D machine, will be measured:

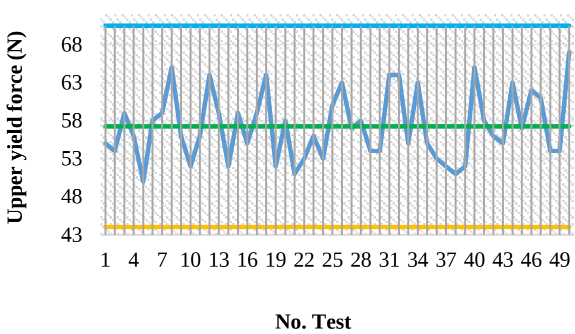
– Upper Yield Force
– Stress
– Deformation

3D printed specimens in vertical position				
No. TEST	UYF (N)	Strees (Pa)	Deformation	Test speed
1	55	700369	0.0002122	5 N/S
2	54	687635	0.0002084	
3	59	751305	0.0002277	
4	56	713103	0.0002161	
5	50	636699	0.0001929	
6	58	738571	0.0002238	
7	59	751305	0.0002277	
8	65	827709	0.0002508	
9	56	713103	0.0002161	
10	52	662167	0.0002007	

Table 4 Measurement of Upper Yield Force, vertical specimen (UYF) (Contribution to the project, unpublished)

During the test, a normal discrepancy is observed, which translates into a correct application of the same, which translates into the following values:

– MEAN: 57.24 N
– UCL: 70.48 N
– LCL: 44 N



Graphic 2 Control Chart UYF vertical
(Contribution to the project, unpublished)

In the test application, it can be observed that the rupture condition occurs at an average value of 57.24N and consequently the elongation characteristics are not present, instead a detachment of section between filaments is observed, which are arranged in a circular way resembling a set of necklaces

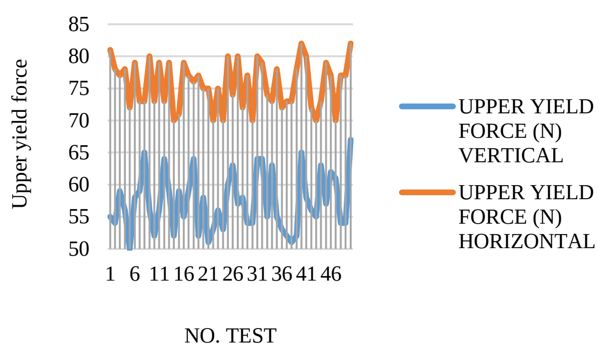
Figure 14 Destructive test vertical position (Contribution to the project, unpublished)

7. Data processing and results

The data comparison reflects a difference focused on the application of force and structural rupture, in which a greater application of this is observed in the 3D printing samples in a horizontal position, compared to the 3D printing samples in a vertical position.

3D print horizontal	3D print vertical
MEAN: 75.64 N UCL: 87.42 N LCL: 63.86 N	MEAN: 57.24 N UCL: 70.48 N LCL: 44 N

Table 5 Comparison of UYF, UCL and LCL data
(Contribution to the project, unpublished)



Graphic 3 Comparison
(Contribution to the project, unpublished)

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Conclusions

The application of destructive tests to a 3D printed element is of vital importance, since through the results of the tests, the best position is determined during the material deposition process, as is the case of the present study, since it can Verify that according to the geometry of the printed body and its position through extrusion, it will determine the tensile strength, this according to the results obtained in the proposed tests, it is concluded that the direction of the filaments of the material of The contribution is significant to the presence of uniaxial yield forces, as long as their direction coincides with that of the extruded filaments.

A recommendation aimed at improving this test measurement process is to check the elastic modulus of the material to be studied, which is significant due to its intrinsic properties and according to its nature, composition and mechanical properties, since these will determine directly the result obtained from the calculations at the time of carrying out the test, likewise it must be considered that the type of material to be printed, as well as the variables to be evaluated, will be according to their properties and depending on the parameterization machine (3D printer) during the material deposition process.

In addition, it is highlighted that, under the action of fluctuating stresses, in this case it consequently generates fatigue, which is evident through visual effects and transversely measurable at the moment of applying the load, which is continuous and constant in unit value, generating a structural phenomenon called "fatigue", which as a result leads to the collapse of the specimen (fracture) SUÁREZ, H. E. J. (2017).

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