Chapter 7 Determination of the correlation factor to achieve inference with greater certainty in the creation of 3D printed prototypes

Capítulo 7 Determinación del factor de correlación para lograr inferir con mayor certeza en la creación de prototipos impresos en 3D

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DOI: 10.35429/H.2023.8.90.97

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A. Marroquín, L. Castillo, J. Olivare sand G.Morado (Coord) Engineering Sciences and Applications. Handbooks-©ECORFAN-México, Querétaro, 2023.

Abstract

3D printing strengthens the manufacturing and design area, since, given the possibility of making product models and prototypes with this technology, it saves on their production and on tests to improve them. The objective of this research is to find the correlation that exists between the models made with 3D Printing and their current materials and the prototype in question. Using a correlation study and physical stress tests, it was possible to obtain a correlation factor that when multiplied by the stress calculated by the SolidWorks Software, a more accurate value is obtained when the prototypes are manufactured.

Correlation Study, Tension Test, 3D Printing Models

Resumen

La impresión 3D fortalece el área de manufactura y diseño, ya que, dada la posibilidad de realizar modelos y prototipos de productos con esta tecnología, se ahorra en su producción y en pruebas para mejorarlos. El objetivo de esta investigación es encontrar la correlación que existe entre los modelos realizados con Impresión 3D y sus materiales actuales y el prototipo en cuestión. Mediante un estudio de correlación y pruebas físicas de tensión, se pudo obtener un factor de correlación que al multiplicarlo por la tensión calculada por el Software SolidWorks, se obtiene un valor más exacto al momento de fabricar los prototipos.

Estudio de correlación, Prueba de tensión, Modelos de impresión 3D

1. Introduction

With the invention of the 3D printer a world of possibilities opened up in the area of manufacturing and design, because even though design software can predict certain static, dynamic and kinematic behaviors, these have a margin of error and it is always better to evaluate in real conditions of both assembly and mechanical testing.

The application of 3D printing for polymers is one of the most widely used at present, but the performance of the elements printed with 3D printers manufactured as prototypes have resulted in very high margins of error with respect to the real state of the process or final product. It should be taken into account that there is no software with structural or functional studies of the 3D printing process, in addition to this, the 3D printing process is to some extent somewhat handmade, since the order, pattern and other printing parameters will depend on the element to be printed and the person who performs the operation.

When building prototypes with 3D printing, there is the problem that there is no test factor to be able to make prototypes that can predict the real behavior (or as close as possible to this). This research is done to decrease the cost of design errors and/or unexpected prototype behavior. This is beneficial for companies, because they will have more accurate data regarding mechanical stresses, which has a direct impact on costs, since it is not necessary to wait to manufacture a model or product, to know if it resists as planned and thus reduce future modifications to them.

1.1 Hypothesis

In the experiment the variable to be measured will be the tensile stress of specimens printed in 3D printer (solid) against the results calculated by spreadsheet and SolidWorks.

X_1= Calculated by spreadsheet and SolidWorks.
X_2=Probes manufactured with 3D printing.
σ= Tensile stress.

Once the variables have been identified it can be identified that:

The null hypothesis defines that, H_0= Both X_1 and X_2 resist the same tensile stress, in other words, there are no changes between the Solidworks simulation and the tensile test on the printed specimens.

$\sigma_{x1} = \sigma_{x2}$

The alternative hypothesis states, H_1=The tensile stress in X_1 is different from that in X_2, with this data a correlation factor can be created.

$\sigma_{x1} \neq \sigma_{x2}$

1.2 Contextual Background

With the advance of technology, inkjet printers were created in 1976, but it was not until 1984 when they began to transform to material printers. This implies a great leap in the manufacturing process because before there were only design softwares, where data is obtained based on statistics of physical tests but limited. With 3D printers it is possible to perform pilot runs and tests before obtaining the molds (exclusively of parts molded with polymers). This adds a new method to perform such process, the problem is that the current software does not have statistics of tests made with 3D printers. Cantrell, J. (2015).

2. Development of the study

2.1 Specimen design

For the specimen design, the DIN 50125 standard is taken as a reference, which is responsible for specifying the geometries and dimensions for mechanical tensile test specimens, these dimensions meet the specifications of the DIN EN 10002-1 standard, which is a standard intended for the creation of mechanical tests. DIN 50125:2004 defines eight types of specimens identified as A, B, C, D, E, F, G and H with the following characteristics:

- Type A. A specimen, of circular section and with smooth and cylindrical ends to be clamped in wedge grips.
- Type B. Test tube, circular section, with threaded ends.
- Type C. Probe, circular section, with shoulder ends.
- Type D. Probe, circular section, with tapered ends.
- Type E. Test piece, flat bar with ends for clamping in wedge grips.
- Type F. Tensile specimens.
- Type G. Tensile specimens.
- Type H. Test piece, flat bar with ends for clamping in wedge grips.

The standard also defines that these specimens must be marked (identification for the test), so that after the test they are identifiable if possible at both ends of the specimens. Based on the theory described above, specimen type E was defined for the method of fastening described in this specimen. In this type of specimen, 12 types of specimens with dimensions according to figure 1 are proposed.

Figure 1 Dimensions of type E tensile specimens.

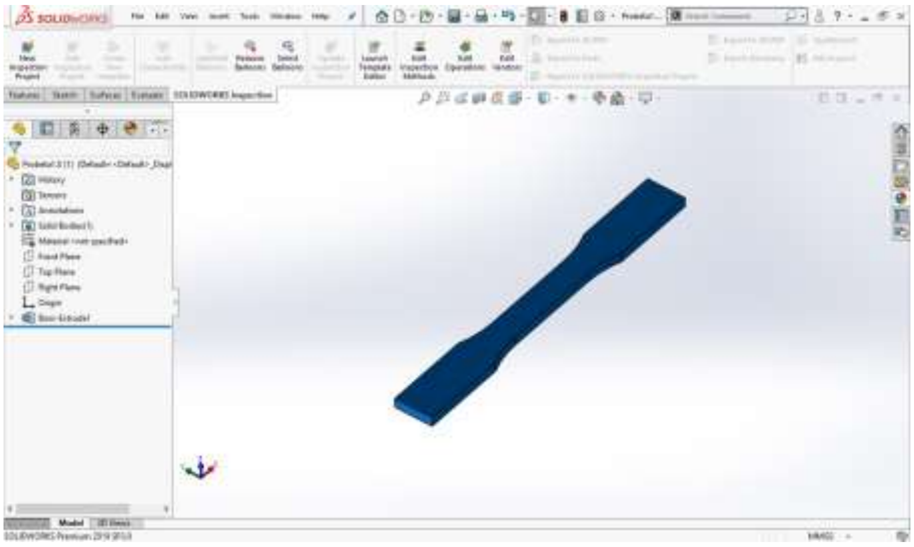
Dimensions in millimetres

a_0	b_0	L_0	B min.	r min.	h min.	L_c min.	L_t min.
3	8	30	12	12	26	38	104
4	10	35	15	12	30	45	120
5	10	40	15	12	30	51	126
5	16	50	22	15	40	64	162
6	20	60	27	15	50	77	197
7	22	70	29	20	55	89	222
8	25	80	33	20	60	102	246
10	25	90	33	20	60	114	258
10	30	100	40	25	70	126	296
12	26	100	34	25	65	127	285
15	30	120	40	25	70	152	322
18	30	130	40	25	70	165	335

Source: DIN 50125:2004

From the options corresponding to the type E specimen, the 3 mm thick specimen is selected, with the help of SolidWorks design software a mathematical model of the selected specimen was made, Figure 2.

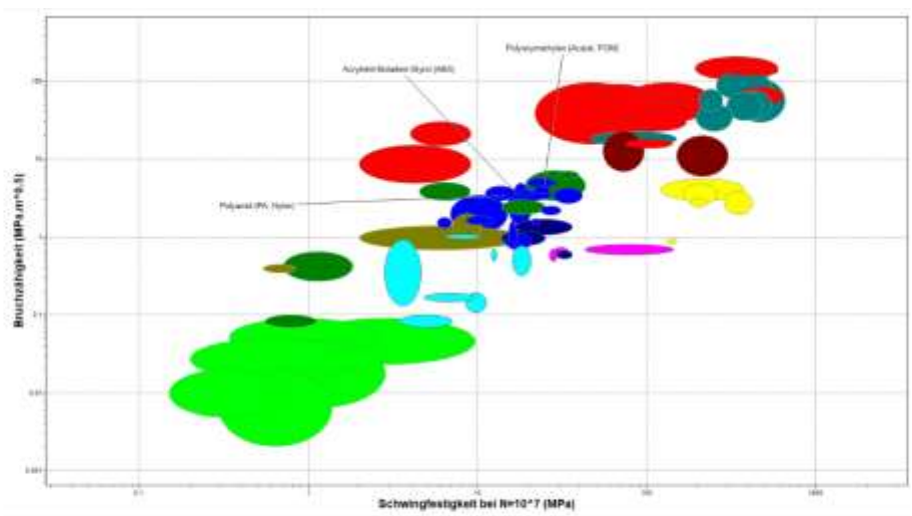
Figure 2 Mathematical model of the specimen in SolidWorks



2.2 Material selection

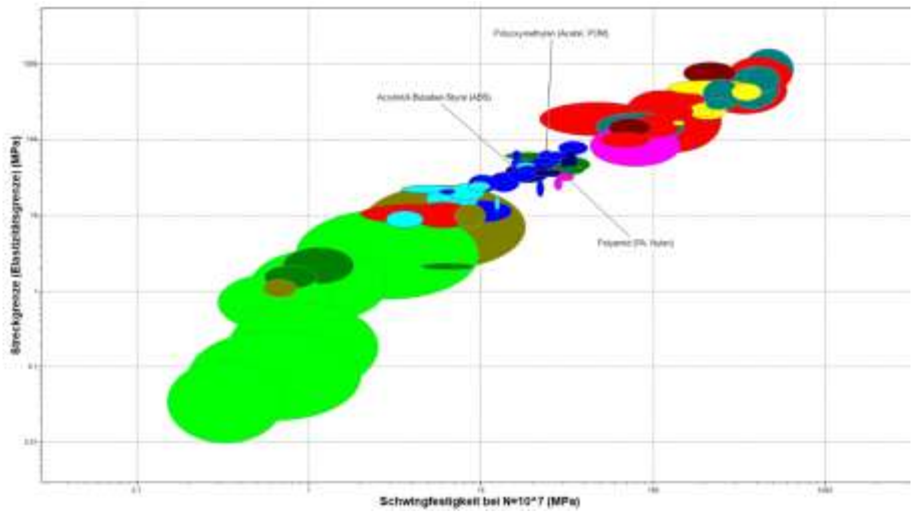
Within the 3D printing world there are many materials such as nylon, PVA, HIPS, ABS, PLA, Flexible, PETG and POM (polycetal). Of all these materials 3 have been selected, POM, ABS and PA Nylon, these were evaluated with the help of CES Edupack 2019 software which is a tool that allows comparing, with logarithmic scale graphs, the properties of the materials, the graphs of stress at break were obtained in Figure 3, elasticity in Figure 4 and traction in Figure 5.

Figure 3 Logarithmic graph of stress at break - cycles, Edupack Software



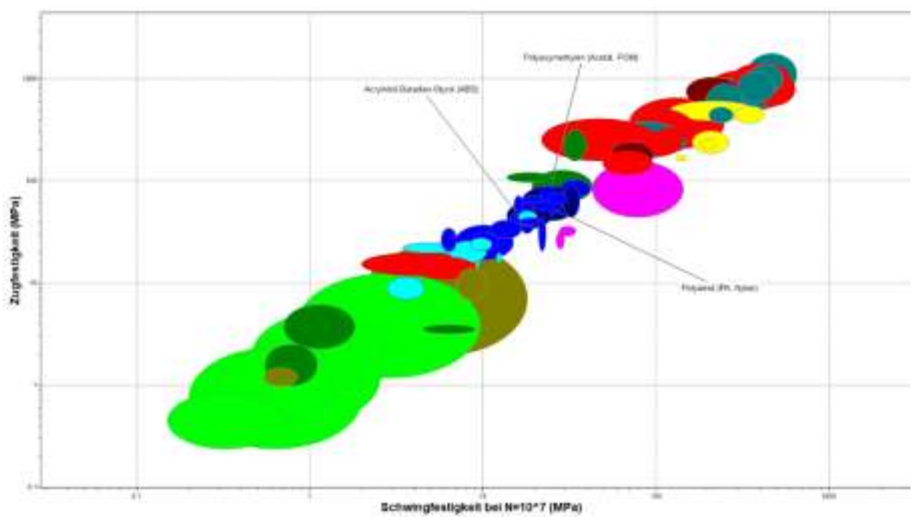
Source: Own Elaboration

Figure 4 Logarithmic graph of elasticity-cycles, Edupack Software



Source: Own Elaboration

Figure 5 Logarithmic graph of stress-cycles, Edupack Software



Source: Own Elaboration

2.3 Printing of the specimen.

The printing of the specimens was performed with an Artillery Sidewinder-X_1 Figure 2 3D printer, it has an aluminum extrusion frame and filament sensor and power failure recovery, 300 x 300 x 400 cm.

The specifications for printing defined by the filament manufacturer are as follows:

- 1.75mm diameter with ±0.03mm variation.
- Hot bed necessarily between 90 and 110 degrees Celsius.
- Printing temperature between 230 and 250 degrees Celsius.

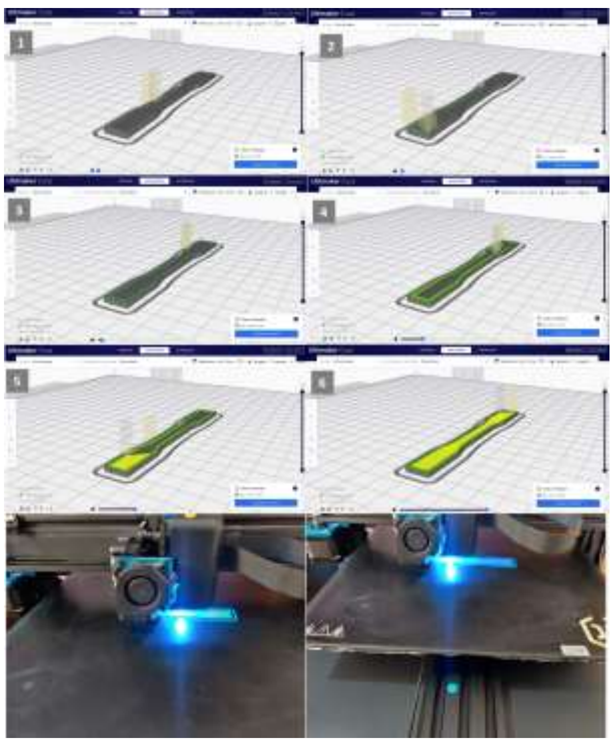
Based on the parameters delivered by the supplier, the specimen geometry and on the theory reviewed, the printing parameters defined in Table 1 have been defined, and with the printing flow shown in Figure 6. C, K. L. (2016).

Table 1 Printing parameters

Parameter	Specification	Unit of measurement
Bracket cantilever angle	45	grados
Support pattern	triángulos	
Support density	5	%
Support Z-distance	0.22	mm
Angle of support branches in the tree	45	grados
Distance of support branches in the tree	1	mm
Diameter of the support branches in the tree	2	mm
Diameter angle of the support on the tree	5	mm
Support placement	Everywhere	location
Printing temperature	240	C
Printing plate temperature	100	C
Printing speed	50	mm/s
Wall speed	25	mm/s
Outside wall speed	20	mm/s
Inner wall speed	25	mm/s

Source: Own Elaboration

Figure 6 Printing flow



Source: Own Elaboration

2.3 Simulation of the mathematical model of the specimen

With the help of SolidWorks design software, a tensile test simulation was performed on the three millimeter specimen E, with the results described in the, table 2, model information, table 3, material properties, table 4, fastening and applied load, table 5, mesh information, table 6, mesh information in detail and table 7, results of the study. Delfanian, B. R. (2016). Cody, S. (2019).

Table 2 Model information, SolidWorks

Model name: Probe E-3		
		
Solid body		
Item evaluated	Evaluated as	Properties
	Solid body	Mass: 0.00324637 kg Volume: 3.18271e-06 m^3 Density: 1.020 kg/m^3 Weight: 0.0318144 N

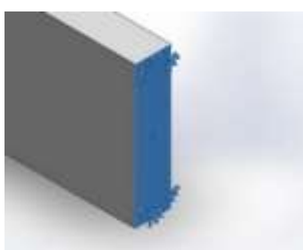
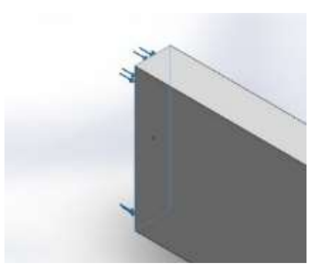
Source: Own Elaboration

Table 3 Material properties, SolidWorks

Reference model	Properties
	Name: ABS. Type of model: Linear isotropic elastic. Tensile stress: 3e+07 N/m^2

Source: Own Elaboration

Table 4 Fastening and applied load, SolidWorks

Fixing name	Fixing image	Fixing details
Fixing		Entities: 1 side. Type: Fixed geometry.
Cargo name	**Image of the load**	**Cargo details**
Force		Entities: 1 side. Type: Apply normal force. Value: 5,000 N

Source: Own Elaboration

Table 5 Mesh information, SolidWorks

Type of mesh:	Solid mesh
Meshing used:	Standard mesh
Jacobin stitches:	4 stitches
Element size:	1.47158 mm
Tolerance:	0.0735788 mm
Mesh plot quality:	High

Source: Own Elaboration

Table 6 Mesh detail information, SolidWorks

Total, of nodes	12052
Total, of elements	7007
Maximum aspect ratio	3.8612
% of elements with aspect < 3	99.9
% of elements with aspect > 10	0
% distortion of elements (Jacobin)	0

Source: Own Elaboration

Table 7 Results of the study, SolidWorks

Name	Type	Min	Max
Traction	VON: Von Mises Tracción	3.920e+07 N/m^2 Node: 77	2.297e+08 N/ m^2 Node: 488

Source: Own Elaboration

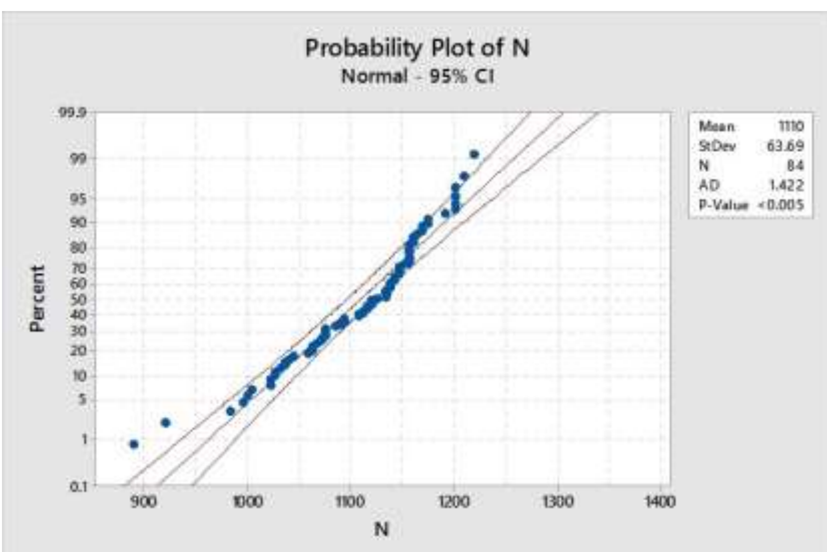
3. Results

3.1 Normality test of the data.

In order to infer in the results of the study, the distribution of the data must be normal, therefore a linearity analysis was performed with the help of Minitab 17 software, in which the data corresponding to the forces necessary to achieve the rupture in the specimens evaluated were used.

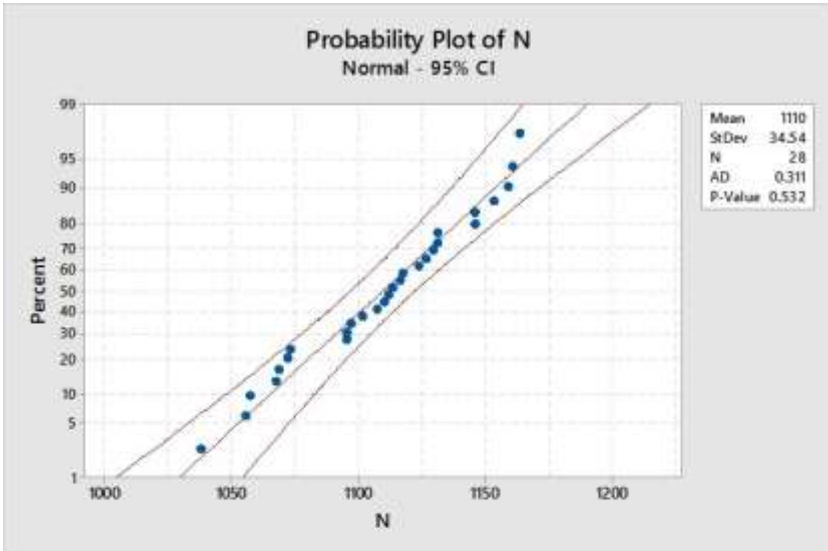
After the linearity test, Figure 6, the P value shows a result of <0.005, for the distribution of the values to be normal it needs to have a P value > at a significance level of 0.05 and as in this case it is lower the data does not follow a normal distribution.

Figure 6 Linearity study 1



To be able to infer in these data it is important to normalize them, which is achieved by creating subgroups, of the 84 samples to which the tensile test was performed were divided into subgroups of 3 pieces to achieve that the data are normal, Figure 7, in this way to infer in these data. In this second linearity test a P value of 0.532 is shown. Being greater than 0.05, it confirms that the values are normal and in this way it can be inferred in these.

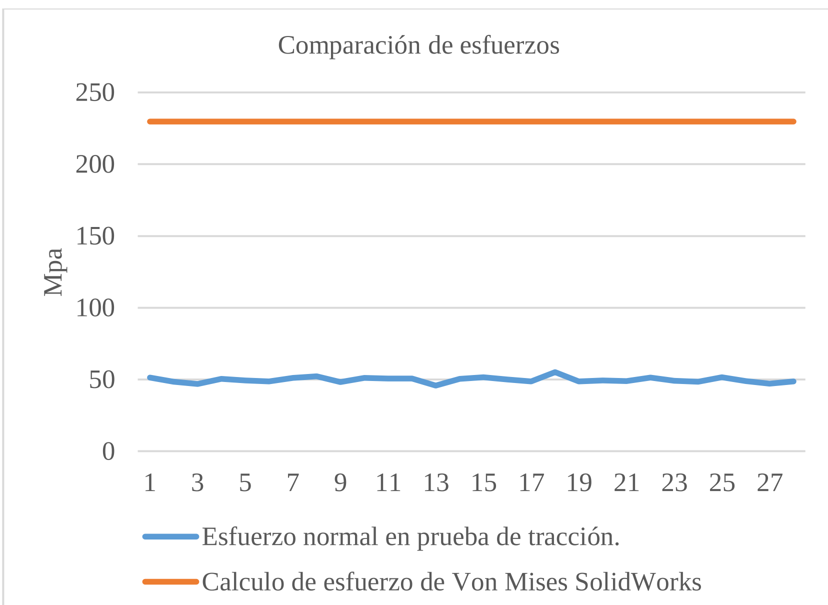
Figure 7 Linearity test 2



3.2 Comparison of calculations against test results

The following graph 1 shows the results of the tests against the stress calculated by the Von Mises method in SoldWorks.

Graph 1 Results of tensile test against Von Mises in SolidWorks.



4. Conclusions and recommendations

The study has a large number of variables, such as 3D printing method, specimen dimensions and material specifications, since the filament suppliers do not show the mechanical properties of their products, only the recommended parameters to use them and some properties by attributes.

The results found in the specimens after the test show a clear effect of the manufacturing method, i.e. the adhesion between filaments is much lower than the adhesion by casting since in the latter the molecules can join internally and accommodate their structures in the case of ABS in an amorphous form while, although the filaments are still amorphous, in 3D printing the union is only external.

Therefore, the null hypothesis is discarded and the alternative hypothesis is approved, which establishes that the tensile stress in X_1 would be different from that of X_2, with this data a correlation factor can be created.

$$\sigma_{x1} < \sigma_{x2}$$

And the values of these two stresses are substituted.

$$\sigma_{x1} = 50\ Mpa < \sigma_{x2} = 229\ Mpa$$

Then it would be possible to define a correlation factor, assuming that the normal stress supported by the specimens only reached 21.83% of the one recommended by the software, therefore the following correlation could be established.

"If the tensile stress calculated by the SolidWorks software is multiplied by a factor of 0.2183, this would be a value closer to the actual value when creating the prototypes."

This is just one advance in this field that has great opportunity for improvement, the next step should be to mold the parts and perform the tensile tests to find a factor that could be used in the design software and thus be able to predict behaviors in prototype parts.

It would also help to increase the sample size to reduce uncertainty and to define a printing pattern that distributes the applied stresses in an equitable way if possible, since in the prototypes these printing patterns will probably be modified and all the results will be affected by this factor.

5. References

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