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EXPERIMENTAL CHARACTERIZATION OF THE MECHANICAL PROPERTIES OF A 3D PRINTED TEST BODY WITH INTERNAL STRUCTURE

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Abstract. *Using data from tensile tests, this study aims to characterize and analyze the behavior of a test body with internal structure in three different formats, honeycomb, diamond and cross, obtained from the melting and deposition process known as 3d printing. The test specimens used in this study follow the ASTM D638-14 standard, as well as the other parameters necessary to perform tensile tests. The specimens were printed with ABS, acrylonitrile butadiene styrene, on a 3D Systems CubePro 3d printer. The tensile tests were performed on a Shimadzu® mechanical testing machine. At the end of the tests sufficient data were obtained to measure the Young's modulus, tensile strength limit, rupture limit, yield strength, maximum displacement of the test specimen and the density for the different internal structure formats.*

Keywords: *3d printing, ASTM D638-14, Honeycomb, Diamond, Cross*

1. INTRODUCTION

Still in the consolidation phase, the melting and layer deposition process, known as 3d printing, is an alternative to conventional machining methods for a reduced number of parts or prototypes. The process of melting and deposition by layers (FDM), consist to melting and deposit material under layers until it reaches the desired shape. Thus, a thickness and orientation of deposited layers, as well as temperature and print speed directly influence the strength of the desired part.

Basically, an FDM impression occurs in a structure where a printing platform moves along the Z axis and extrusion nozzle moves along the X and Y axes. Such a deposition process creates deposition lines, which overlap, shape the desired part. On other hand the type of deposition generates an anisotropic body since its properties change according to the orientation of the extrusion layer. It can be compared as a composite material since the mechanical properties change according with the fiber orientation however, the print layer orientation can be changed according to the required work strength.

The possibility of creating an object by layers allows us to change an internal structure of objects that conventional machining processes is cannot, therefore, a body endowed with internal structure that allows to decrease the density and to maintain the material resistance is feasible. The adaptation of structures known as honeycomb, diamond and cross, allow to minimize the weight and cost of manufacture. The common visual characteristics of the aforementioned structures consist of a matrix of hollow hexagonal cells, which are either angular or interlaced. Consequently, these structures are used on flat and curved surfaces when a high strength-to-weight ratio is required, with wide application in the industry in general.

2. METODOLOGY

In order to set the regulatory standard to be used a survey was conducted among the standards for tensile testing polymer and articles about mechanical testing specimens obtained by 3D printing. Accordingly, the standards for ISO tensile tests polymers 527-2, ASTM D638-14 and NBR 6152, were analyzed and we selected those more suited for the purpose of this paper, ISO 527-2 and ASTM D638-14. To select a standard to standardize the tests performed, a parallel was created between the published articles that address this theme as Rodriguez, Jose and Thomas (2001) also Ziemian, Sharma (2012) and the norms used by them to create a parallel and between the results obtained by the present study. Therefore, ASTM D638-14 was chosen to standardize the performed tests.

The tests performed in this study were conducted on a Shimadzu Autograph AG series mechanical testing machine and standardized by ASTM D638-14. The specimens were made in a 3D Systems CubePro printer using ABS as a print material. The impression was made in a thermally controlled atmosphere at 75 °C to avoid the process of warping process. The extrusion temperature of the ABS was defined at 230 ° C with the average deposition rate of 1.75 g/min.

The test body size was defined by the type 1 geometry specified in ASTM D638 - 14. To achieve greater fidelity to the dimensions of the specimen, a print resolution of 0.07 mm was set as the Figure 1 shows.

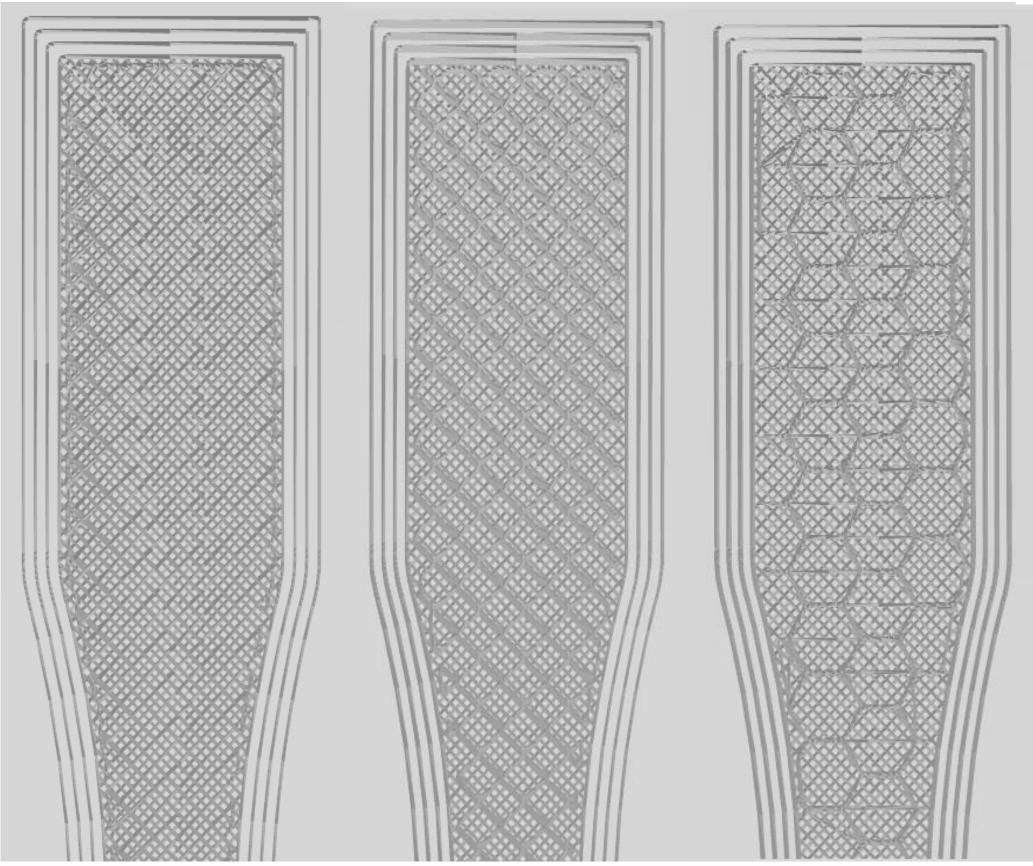

Figure 1. Cross, Diamond and Honeycomb test specimens.

The tensile test was performed according to ASTM D638-14 at a test speed specified at 5 ± 25% mm / min. The mechanical properties for a fully solid test piece from an ABS cartridge for the CubePro ®, Tab. (1), printer following the ASTM D638 - 14 standard was used as a basis for comparison.

Table 2. mechanical properties for a fully solid test body from an ABS cartridge.

	Tensile strength	**Ductility**	**Young's Module**
Test method	ASTM D638	ASTM D638	ASTM D790
Unit of measurement	Mpa	%	Mpa
ABS	22,06	6	1834,00

Tests conducted on eighteen specimens were analyzed according to Callister (2016) and Smith (2012). The Young's modulus was calculated along the linear portion of the Strain/Deformation curve as shown in Eq. (1), the yield strength obtained by the 0.2% offset method for polymers and the density was also calculated according to Eq. (2), the sample volume was obtained by CAD file and weight data provided by a precision balance. The tensile strength and the rupture limit, Fig. (2), coincide, respectively, with the maximum point of the curve and the point of rupture of the material.

$$E = \frac{\sigma(\varepsilon)}{\varepsilon} = \frac{F/A}{\Delta L/Li} = \frac{F \times Li}{A \times \Delta L} \tag{1}$$

Where:

E, is the Young's modulus;
F, is the force exerted on an object under tension;
A, is the actual cross-sectional area, which equals the area of the cross-section perpendicular to the applied force;
ΔL, is the amount by which the length of the specimen changes;
L_i is the original length of the test body;

$$\rho = \frac{M}{V} \tag{2}$$

Where:

ρ, is the density;
M, is the test body mass;
V, is the test body volume;

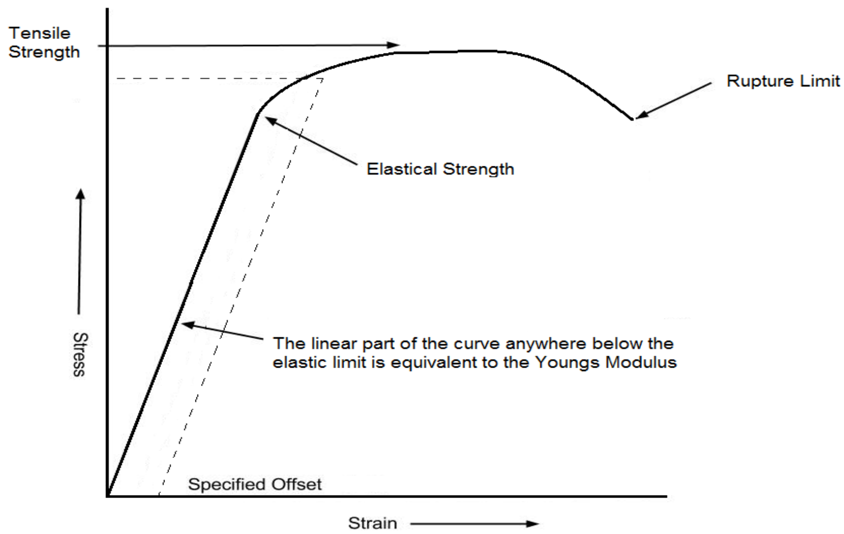

Fig 2. The tensile strength, rupture limit and offset method.

3. RESULTS

The following tables show the mechanical properties results for the ABS polymer tensile test. Tab. (2) for the cross internal structure test body, Tab. (3) for the diamond internal structure and Tab. (4) for the honeycomb internal format. The *stress x strain* graphics listed below are, respectively, in accordance with the internal structures. Fig. (3) for cross structure, Fig. (4) for diamond internal structure and Fig. (5) for honeycomb format.

Table 2. Experimental results of tensile test for type 1 polymer test body according to ASTM D638-14. Cross internal format.

Samples	Young's Module (MPa)	Tensile strength (MPa)	Yield Strength (MPa)	Breaking Strength (MPa)	Maximum Displacement (mm)	Density g/cm³
C1	1207.861	22.226	15.151	19.556	0.0498	0.998
C2	1190.220	22,926	14.457	19.216	0.0435	1.017
C3	1057.449	20.877	13.753	17.993	0.0481	0.982
C4	968.429	16.291	10.953	15.233	0.0363	0.998
C5	1088.596	22.117	14.057	19.060	0.0435	0.998
C6	1078.711	20.879	13.898	18.015	0.0485	0.996

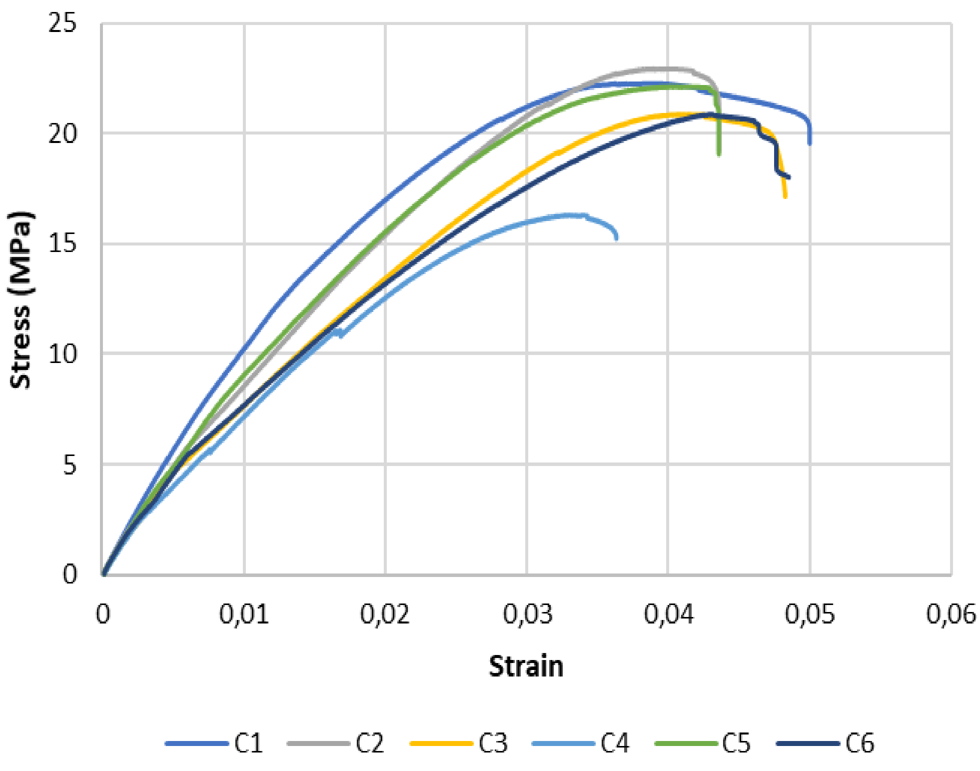

Figure 3. *Stress x Strain* for type 1 polymer test body according to ASTM D638-14. Cross internal format.

Table 3. Experimental results of tensile test for type 1 polymer test body according to ASTM D638-14. Diamond internal format.

Samples	Young's Module (MPa)	Tensile strength (MPa)	Yield Strength (MPa)	Breaking Strength (MPa)	Maximum Displacement (mm)	Density g/cm³
D1	1191.529	19.317	12.914	16.063	0.0331	0.822
D2	1194.790	24.020	14.461	16.212	0.0398	0.851
D3	1359.974	25.259	15.168	20.592	0.0409	0.870
D4	1278.332	24.412	13.990	20.358	0.0421	0.852
D5	1314.283	24.346	13.851	19.878	0.0422	0.852
D6	1312.295	24.209	12.528	17.863	0.0431	0.822

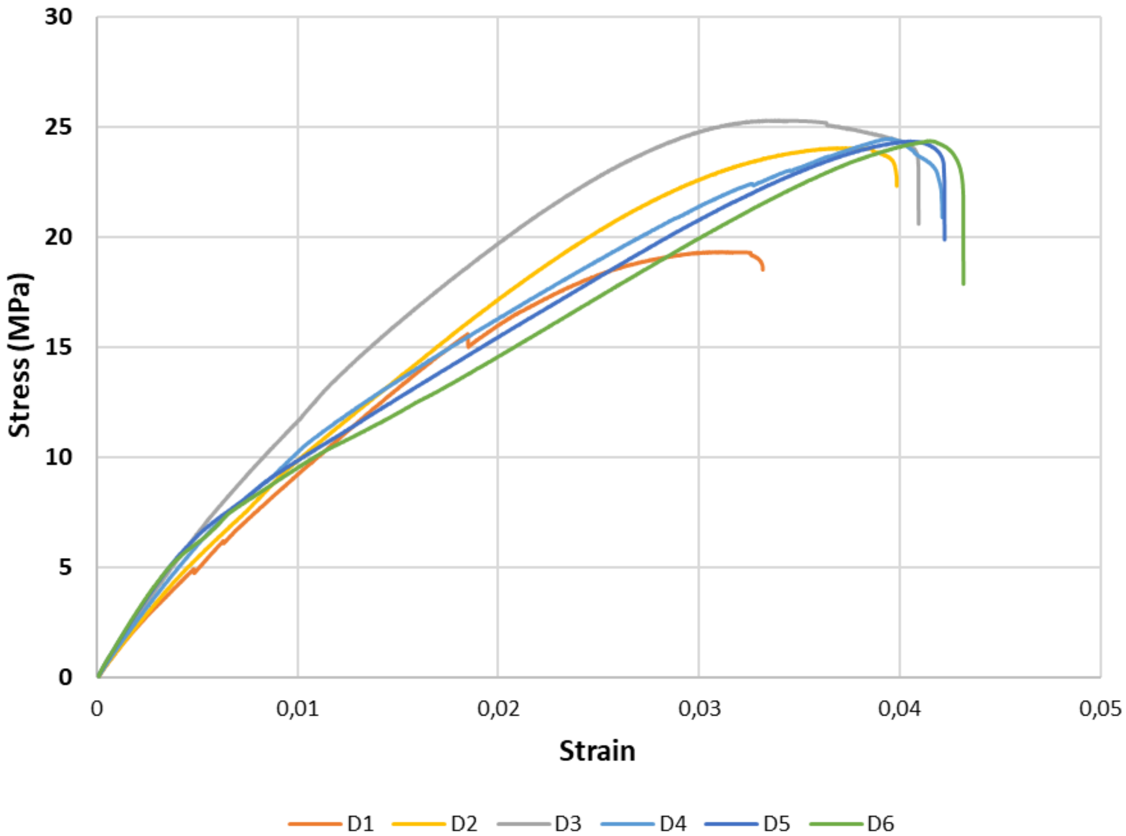

Figure 4. *Stress x Strain* for type 1 polymer test body according to ASTM D638-14. Diamond internal format.

Table 4. Experimental results of tensile test for type 1 polymer test body according to ASTM D638-14. Honeycomb internal format.

Samples	Young's Module (MPa)	Tensile strength (MPa)	Yield Strength (MPa)	Breaking Strength (MPa)	Maximum Displacement (mm)	Density g/cm³
H1	1255.670	22.480	17.386	18.833	0.0472	0.956
H2	1182.425	21.013	16.065	20.325	0.0393	0.962
H3	1085.716	11.459	9.700	10.829	0.0337	0.960
H4	1143.804	21.583	13.972	20.423	0.0430	0.964
H5	1218.280	21.990	15.017	17.175	0.0547	0.956
H6	1139.874	19.785	13.429	18.166	0.0413	0.962

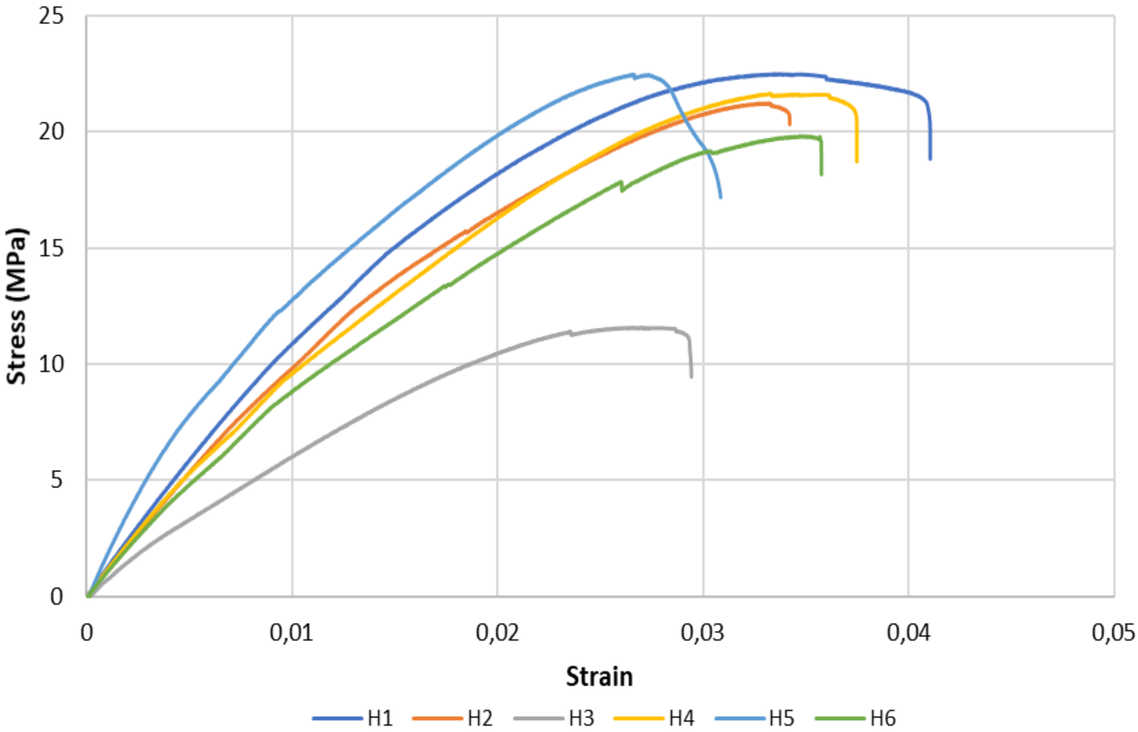

Figure 5. *Stress x Strain* for type 1 polymer test body according to ASTM D638-14. Honeycomb internal format.

When comparing the results obtained through the tensile test of the test bodies with internal structures against completely solid test specimens, there are equivalence between the results of both tests. However the great improvement is the diference between density. The volume for a ASTM D638-14 type 1 specimen is 10,498 *cm³* and the density of ABS is 1,060 *g/cm³* according with Cambridge Engineering Department (2003) thus the total mass of a type 1 test body is 11,127 *g*. The average density, for each structure as the average mass is shown below in Tab. (4)

Table 5. comparison of the density, mass and tensile strength of test bodies with internal structure and specimen completely solid.

Structure type	Average density (g/cm³)	Average mass (g)	Mass percentage reduction (%)	Average tensile strength (MPa)
Cross	0.998	10.470	5.900	20,886
Diamond	0.849	8.912	19.900	23,593
Honeycomb	0.960	10.078	9.420	19,715

4. CONCLUSION

It is noted that the test body with a diamond-shaped internal structure obtained a mass reduction of 19.90% and maintained a tensile strength equal to the tensile strength of an ABS cartridge for 3d printer. It is also possible to observe that although the other formats have a mass reduction compared to a totally solid test body they also showed a slight tensile strength reduction. In view of the presented data it is pertinent to carry out new tests such as compression, bending and impact tests in order to compare the other material properties and to determine if the reduction of mass in bodies with internal structure affects the value of such properties.

This results corroborates the applicability of replacing fully 3d printed solid bodies, with internal structure in order to decrease the weight and maintain the mechanical properties.

5. ACKNOWLEDGMENTS

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7. RESPONSIBILITY NOTICE

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