FLEXURAL TESTS OF ONYX COMPOSITE SYSTEM USING SPECIMENS WITH DIFFERENT SIZES AND SHAPES FOR THE INNER STRUCTURE

TESTES DE FLEXÃO EM PROVETES DE COMPÓSITO ONYX COM DIFERENTES TAMANHOS E FORMAS NA SUA ESTRUTURA INTERNA

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ABSTRACT

There has been a growing interest in characterizing 3D printed specimen to determine their structural integrity behavior. The main aim of this study is to observe the mechanical properties of specimens created by 3D printing using composite Onyx, a fusion of engineering nylon and chopped carbon fibers. Performed tests measure the force required to bend the specimens and collected data used to select size and shape of the inner structure optimizing material's consumption. Nine specimens sized according to ISO 178 are considered. Tests carried out according to ASTM D790 and next ISO 178. For a 5% deflection, data registered when sample reaches 5% deflection or breaks before 5%. If the sample can withstand the 5% deflection, the test will continue by norm ISO 178 and stopped when the specimens breaks. Test results organized in tables and graphs are maximal force and force by 5% deflection plus the value of consumed volume of material. By considering the ratio of Force by 5 % deflection to volume of material, it is possible to address stiffness effectivity. On the other hand, ratio of maximal force to volume of material can take into account the straight effectivity.

Keywords: *Flexural test, Inner Structure, Onyx, Optimization.*

RESUMO

A caracterização de provetes produzidos por impressão 3D para determinar o seu comportamento estrutural tem tido um interesse crescente. O principal objetivo deste estudo é registar as propriedades mecânicas de provetes produzidos por impressão 3D usando o material compósito Onyx, uma fusão de engenharia do nylon e fibras de carbono. Os testes realizados pretendem avaliar a força necessária para dobrar diferentes amostras e os resultados podem ser usados para selecionar o tamanho e a forma da estrutura interna, otimizando o consumo do material. Nove amostras dimensionadas de acordo com ISO 178 são consideradas. Os testes foram realizados de acordo com ASTM D790 e seguindo ISO 178. Para uma deflexão de 5%, os resultados são registados quando a amostra atinge 5% de deflexão ou ocorre a rotura antes dos 5%. Se o provete consegue suportar uma flexão de 5%, o teste vai continuar pela norma ISO 178 terminando com a rotura do provete. Os resultados dos testes organizados em tabelas e gráficos são: força máxima e força de flexão a 5%, e ainda o valor do volume de material utilizado. Considerando a razão da força de flexão a 5% para o volume de material, é possível estabelecer a efetividade de rigidez. Por outro lado, a razão da força máxima para o volume de material permite calcular a efetividade direta.

Palavras Chave: *Teste à flexão, estrutura interna, Onyx, otimização.*

1. INTRODUCTION

The flexural test measures the force required to bend a beam under three point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material’s stiffness when flexed.

The sample lies on a support span and the load is applied to the center by the loading nose producing three point bending at a specified rate. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test. By optimizing the size and shape of the inner structure, it is possible to ensure the choice of the right structure for a given issue with regard to material consumption. The specimens are sized according to ISO 178. The test is carried out according to ASTM D790 and next ISO 178. Test will measure the force required to bend the sample and test is stopped when the specimen reaches 5% deflection or the specimen breaks before 5%. If the sample can withstand the desired deflection, the test will continue by norm ISO 178 and the test is stopped when the specimen breaks. For the Specimen shape will used size from norm ISO 178. It is 10mm x 4mm x 80mm.

2. MATERIAL AND METHOD

2.1. Composite material Onyx

Onyx is a composite filament for Mark Two Enterprise 3D printers. A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. Onyx is not just only another plastic material, it’s actually a fusion of engineering nylon and chopped carbon fiber. This chopped carbon fiber filament adds stiffness to 3D printed parts, not only providing micro-carbon reinforcement to keep parts true to their dimensions, but also giving parts a smooth, matte black finish. Onyx have properties, where are valued in 3D printing: hardness, nice surface finish, and good adhesion so parts don’t split along layer seams. Onyx is about 3.5 times stiffer than standard nylon because of the micro-carbon reinforcement. Because it also contains nylon, the engineering toughness and wear resistance is comparable as well, and the material has a heat deflection temperature of 145 °C. Onyx is can used with high-strength fibers - carbon fiber, Kevlar, fiberglass, or HSHT fiberglass, to even further strengthen parts. Table 1 shows some properties of Onyx.

Table 1 - Datasheet of Onyx by norm ASTM D790

Materials	Flexural Strength (MPa)	Flexural Modulus (GPa)	Specific Weight (g/cm^3)
Onyx	81	2,9	1,18
Nylon	32	0,84	1,10

2.2. 3D printing Fused Filament Fabrication (FFF)

Fused filament fabrication is a 3D printing process that uses a continuous filament of a thermoplastic material, as shown in Figure 1. Filament is fed from a large coil through a moving, heated printer extruder head, and is deposited on the growing work. The print head is moved under computer control to define the printed shape. Usually the head moves in two dimensions to deposit one horizontal plane, or layer, at a time. Print head is then moved vertically by a small amount to begin a new layer. The speed of the extruder head may also be controlled to stop and start deposition and form an interrupted plane without stringing or dribbling between sections.

2.3. Specimens

Specimens are created from material Onyx with additive technology Fused Filament fabrication. Specimens have 80mm x 10mm x 4mm dimensions. Their differences are in shape of inner structure and dimensions of shape, according Figures 2, 3 and 4.

First group represent shape hexagonal (H), second group is square (S) and third group is triangles (T). This shapes have others sizes with parameter "l". Final number of types of the specimen is 9. Three different shapes (H, S, T) multiplied by 3 others sizes (2, 4, 6). Thickness fringes and wall between shapes is 0.8 mm. Settings by 3D printing are 2 layers by 0.4mm and 4 roof and floor layers.

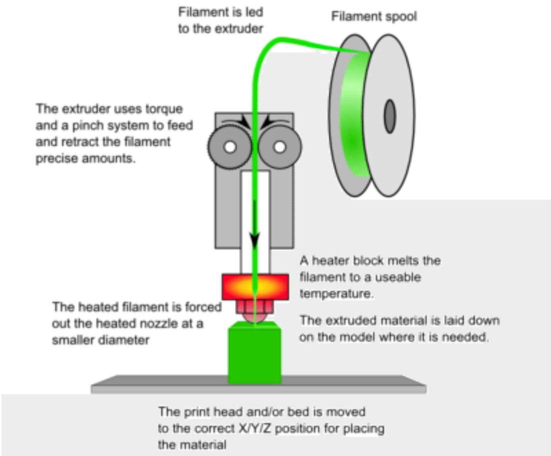

Fig 1: 3D printing FFF

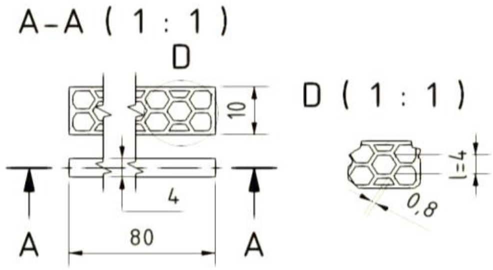

Fig 2: Specimen with hexagonal shape and 4 mm dimension of inner structure

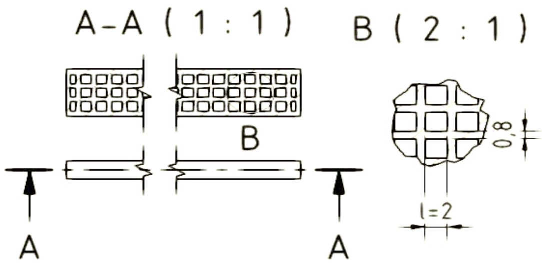

Fig 3: Specimen with square shape and 2 mm dimension of inner structure

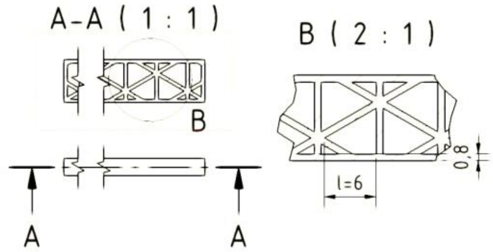

Fig 4: Specimen with triangle shape and 6 mm dimension of inner structure

3. RESULTS

The flexural results obtained from three point bending tests are analyzed. The main objective is to compare the results for different shapes and sizes. The numerical results are in the Table 2 and plotted in graphs from Figure 5 to Figure 9.

The formulae presented below is used to calculate the effectiveness of individual internal adopted structures in terms of shape and size. In the first case, the stiffness effectivity is expressed by equation (1); and in the second case, the strength effectivity is expressed by equation (2). In both cases, efficiency is calculated as the ratio of force to volume, as follows

$$\mathrm{E}_{Stiffness} = \frac{F_{5\%}}{V} \quad (1)$$

$$\mathrm{E}_{Strength} = \frac{F_{Max}}{V} \quad (2)$$

Table 2: Results from flexural test

Specimens	**Force by 5%** $F_{5\%}$ (N)	**Maximal Force** F_{Max} (N)	**Volume V** (mm^3)	**Stiffness Effectivity** Eq.(1)	**Strength Effectivity** Eq.(2)
H2	10,87	52,16	2390	0,0045	0,0218
H4	9,55	48,61	2075	0,0046	0,0234
H6	8,76	44,68	1995	0,0043	0,0224
S2	8,12	43,22	2393	0,0034	0,0180
S4	7,72	41,47	2130	0,0036	0,0195
S6	7,49	39,70	2077	0,0036	0,0191
T2	8,91	45,86	2525	0,0035	0,0181
T4	8,16	42,51	2270	0,0035	0,0187
T6	7,69	39,73	2105	0,0036	0,0189

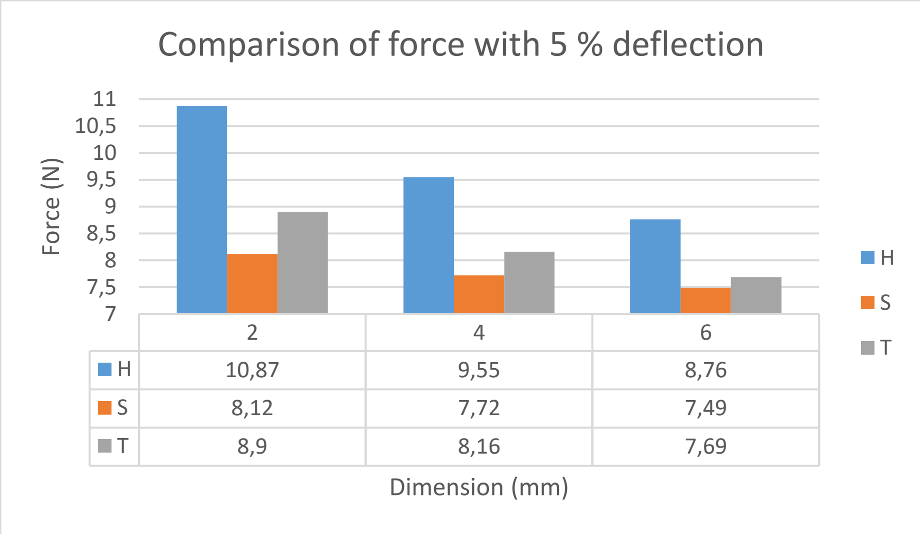

Fig 5: Comparison of Force with 5% deflection for specimens with different inner structures

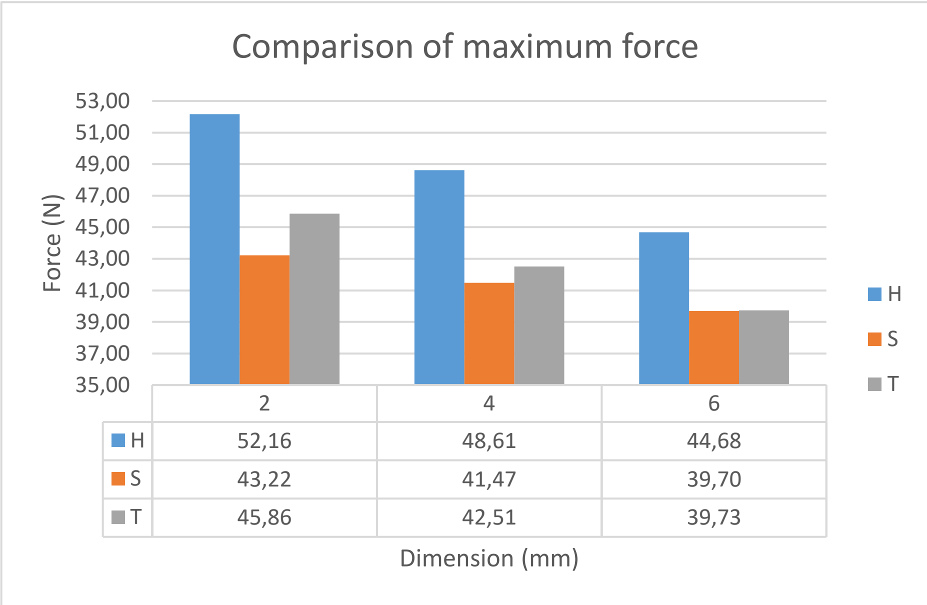

Fig 6: Comparison of Maximum Force for specimens with different inner structures

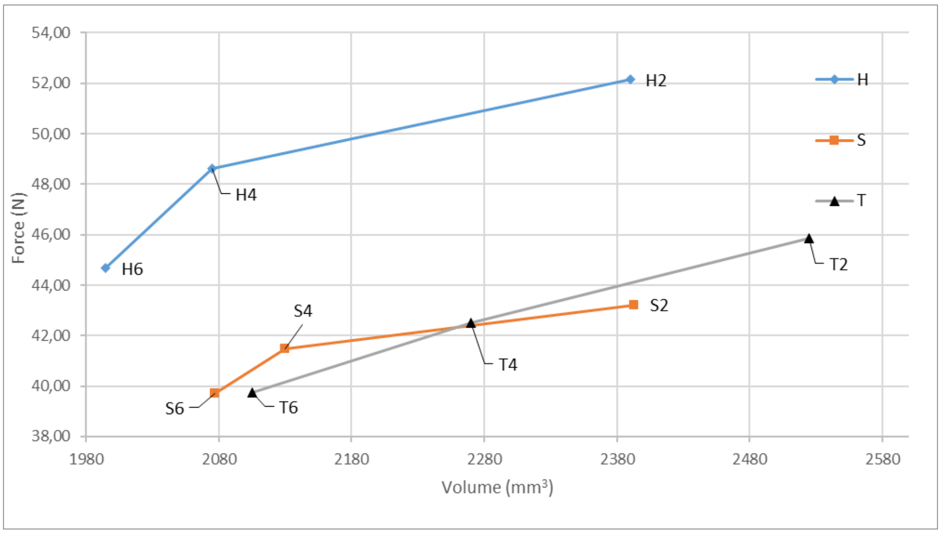

Fig 7: Comparison of Maximum Force by Volume for specimens with different inner structures

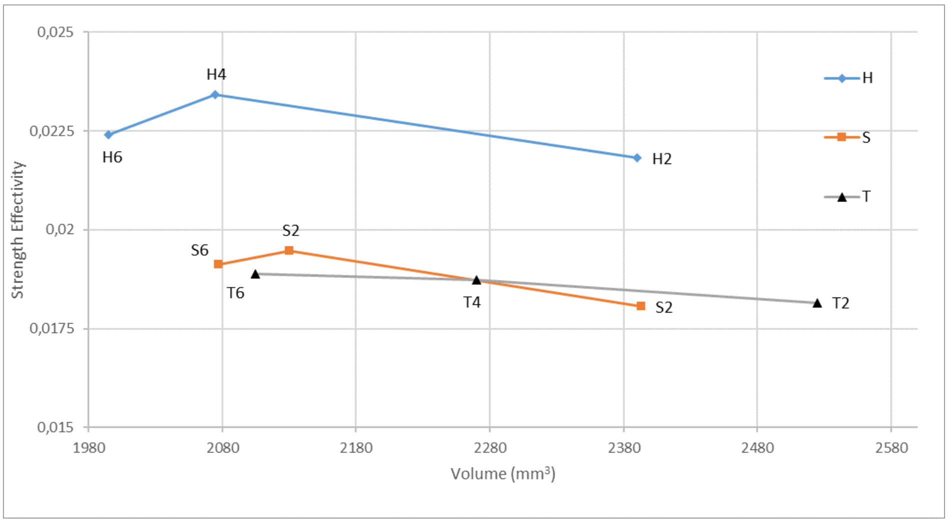

Fig 8: Comparison of Strength Effectivity by Volume for specimens with different inner structures

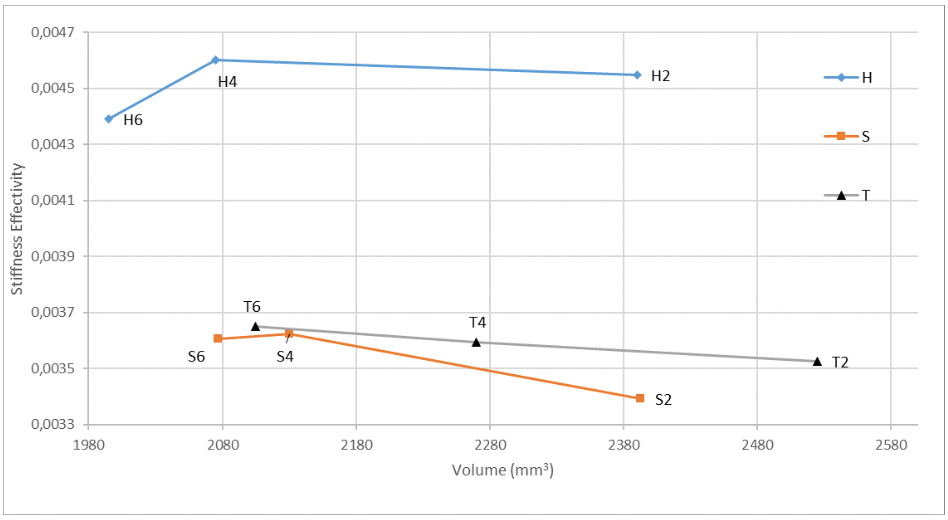

Fig 9: Comparison of Stiffness Effectivity by Volume for specimens with different inner structures

4. CONCLUSION & DISCUSSION

In plotted graphs, it is possible to see the differences between specimens. Generally, by observation of the results it is important notice that with increasing size structure volume the volume of material decrease. Naturally, the best inner structure have 2 mm of dimension (l=2mm), because this dimension have more volume of material than specimens which have bigger dimension of inner structure. By optimizing the shape and size of the internal structure, it is possible to save material. Therefore, it has been found that it is important to design and change the shape and size of the internal structure as needed for practical use.

In Table 2 it possible to see the maximal force from flexural tests for individual specimens. Maximal value force was for hexagonal shape of inner structure with 2 mm dimension (H2) approximately 52N and on contrary the minimum was for square shape of inner structure with 6 mm dimension (S6) 39,70N.

The graph of Figure. 5 shows comparison of forces with 5 % deflection for all specimens. Comparison for specimens with different inner structures shows similar aspect than in the next graph Figure. 6 in which it was using maximal force. The difference is in the value of force. For 5 % deflection the maximum value was for hexagonal shape of inner structure with 2 mm dimension (H2) and 10,87N and the minimum value was for square shape of inner structure with 6 mm dimension (S6) and 7,50 N.

From all graphs it is possible to clearly identify the best internal structure, which is a hexagonal (H) shape. For this hexagonal shape of inner structure the best results in values for Maximal Force and Force by 5% deflection corresponds to a structure with 2 mm of size (H2).

From an effective point of view (Stiffness and Strength), the best dimension of shape is equal to 4mm (H4). In hexagonal shape of inner structure, it is possible to see nonlinear curve as shown from Figure 7 to Figure 9.

The comparison of results between square (S) and triangle (T) shapes of inner structure were very similar. However, when comparing material consumption, the structure of Type S would be better. The worst results were present in the T structure. In square (S) shape of inner structure it is possible to see a nonlinear curve. On the other side in triangle shape of inner structure, it might record linear curve.

To sum up we can conclude, that by optimizing the shape of inner structure and using a speed of 4N/s on the application of flexural load it has been achieved the best results for the hexagonal shape of inner structure. Furthermore, the worst results are obtained for the triangle shape of inner structure. Moreover, it is possible to state, that material consumption directly influences the mechanical properties of the specimen.

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