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Influence of long and short glass fiber on the mechanical behaviour of a single cell metamaterial

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Abstract. Additive manufacturing is presenting new challenges in various aspects of part production. Among these, the potential benefits derived from material complexity have been growing in recent years, especially when using polymeric materials. In fact, mixing polymers with long/short fibres lead to moderate to significant improvements in the mechanical properties of the parts. The degree of improvement strongly depends on the part geometry and can become critical in the case of a workpiece with a repeating pattern, such as metamaterials. In this preliminary research, the authors investigate the mechanical performance of a single- hourglass cell which is a common auxetic geometry used to achieve a negative Poisson ratio in metamaterials. Nylon was used as the matrix, and glass as the fibre. FFF additive process was used to produce samples with different cell designs (in width, size, inclination) and the nature of the fibres (long and short). The results were analysed using statistical methods.

Introduction

Auxetic materials are a unique class of materials that exhibit a counterintuitive property: they expand in all directions when stretched. Unlike conventional materials, which contract when stretched, auxetic materials have a negative Poisson's ratio, which means that they become wider and thicker when subjected to tensile forces [1,2].

One of the most interesting properties of auxetic materials is their ability to absorb impact and dissipate energy more effectively than conventional materials. This makes them ideal for use in a wide range of applications, including protective gear, shock absorbers and insulation [3].

Another advantage of auxetic materials is their ability to conform to complex shapes and surfaces, making them useful in applications where conventional materials would be difficult to use. For example, auxetic foam can be used in the design of customized medical implants, while auxetic fabrics can be used in the production of high-performance sports clothing [4, 5].

In Figure 1a there is an example of auxetic hourglass geometry while in figure 1b their behavior bulk behavior under compression load is represented.

(a) Auxetic cell design (b) Behaviour scheme under tensile strength

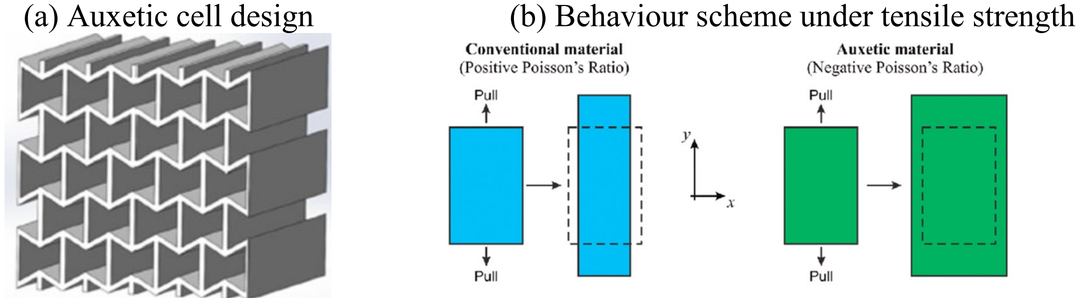

***Figure 1**. Design and characteristic of auxetic materials.*

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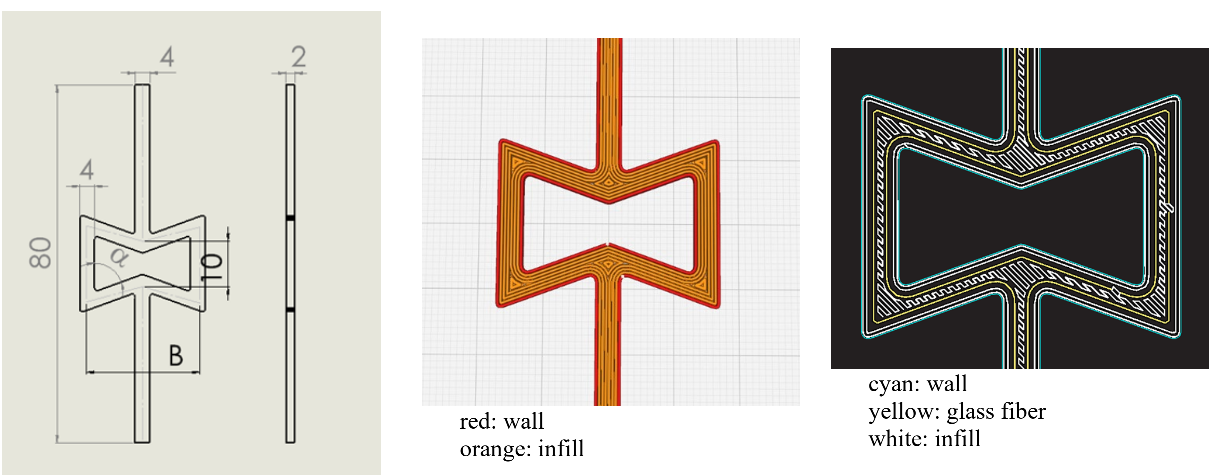
Due to their complex shapes, additive manufacturing proves to be a more advantageous geometry to produce auxetic materials. Various studies can be found in literature regarding the characterization of auxetic cells produced through the Fused Filament Fabrication (FFF) process [6-10]. Mainly, materials such as PLA and Nylon. However, FFF can produce composite materials with high mechanical properties by extruding carbon, glass, or Kevlar fibers into the component. Fibers can be supplied as long or short, significantly changing the material properties. From the literature, it is known that long fiber composites have considerably better performance [11]. It should be noted that such an improvement has been verified on relatively simple geometries (rectangular specimens, dog-bone specimens, cylindrical specimens), and it is not yet clear if the gap between long and short fibers still holds true for complex geometries such as those of auxetic structures.

The aim of this research was to compare the mechanical properties of auxetic cells with a specific geometry created through additive manufacturing using long and short glass fiber composite materials. Through the FFF 3D printing technique, samples with a hourglass geometry were fabricated to study their tensile behavior, focusing on the analysis of the forces required to deform the sample, stiffness, and measured Poisson's ratio.

Materials and Methods

In this research, an hourglass geometry was used as an auxetic cell to analyse the performance of short and long fiber composites. Three levels of cell angle α (60°, 70°, and 80°) and three cell widths B (20 mm, 30 mm, and 40 mm) were designed, resulting in nine different combinations; thickness of sample was equal to 2 mm. Each of these combinations was fabricated using fused filament fabrication technology. The S3 printer provided by Ultimaker was used to print samples using nylon reinforced with short glass fiber (SGF), while the Mark2 printer provided by Markforged was used to produce samples using nylon reinforced with long glass fiber (LGF). The quantity of fiber designed for LGF was equal in weight with SGF. Figure 2a shows the auxetic cell design, while figures 2b and 2c show the different path strategies used for SGF-Nylon and LGF-Nylon, respectively



(a) (b) (c)

***Figure 2**. a) Sample geometry, b) SGF-Nylon and c) LGF-Nylon infill strategies.*

After production, tensile tests were conducted to measure the performance of the samples. The tests were performed using the Instron 3360 machine, with a gauge speed set at 1 mm/min. A reference pattern was applied on the surface of each sample before the tests and a digital camera was used to observe the tensile tests and acquire digital images. GOM correlate software was then used to evaluate the sample deformations. Finally, the maximum force and Poisson's ratio values were estimated.

Results and Preliminary Conclusion

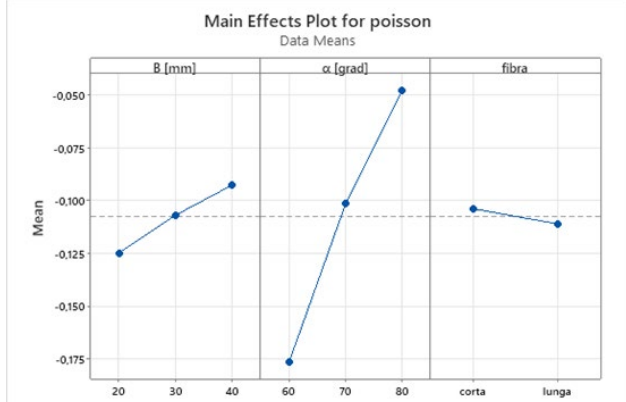
Figure 3 plots preliminary results in terms of main effective plots and Tukey range test.
Regarding the Poisson ratio of the sample:

- is directly proportional to the cell dimension B and the α value.
- the type of fibre is not influent.

Regarding the Maximum force:

- is directly proportional to the cell dimension B, while α angle is not influent.
- it is higher in short fibre samples.

Overall, the preliminary results suggest that the type of fibres (short or long) does not influence the auxetic behavior in hourglass cells. On the contrary, the geometry of the cell itself determines the value of the Poisson ratio. The influence of the fiber type is more significant on the stability of the cell. In fact, the point of maximum force corresponds to the moment at which geometrical instability occurs and the sample is no more planar. Therefore, samples with short fibers are able to withstand higher loads before instability.

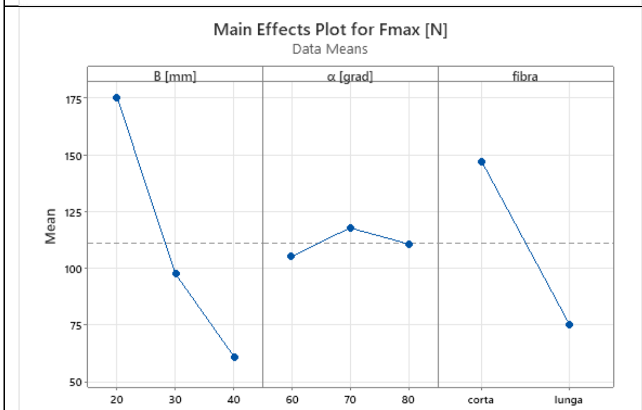


B [mm]	N	Mean	Grouping
40	18	-0,092556	A
30	18	-0,106833	B
20	16	-0,128608	C

α [grad]	N	Mean	Grouping
80	18	-0,047611	A
70	17	-0,102364	B
60	17	-0,178021	C

fibra	N	Mean	Grouping
corta	26	-0,104243	A
lunga	26	-0,114422	B

Means that do not share a letter are significantly different.



B [mm]	N	Mean	Grouping
20	18	175,323	A
30	18	97,542	B
40	18	61,049	C

α [grad]	N	Mean	Grouping
70	18	117,875	A
80	18	110,760	A
60	18	105,280	A

fibra	N	Mean	Grouping
corta	27	147,210	A
lunga	27	75,399	B

Means that do not share a letter are significantly different.

Figure 3: Preliminary results

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