Designing Anepectic metamaterials

4th DOCTORAL CONGRESS IN ENGINEERING

João Cardoso[a], Patrícia Almeida[a], Guilherme Cândida[a], Gonçalo Catatão[a], Frederico Páscoa[b], Daniela Silva[a], João P. Borges[a], Carla Machado[b], Alexandre Velhinho[b]

U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

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Introduction

Metamaterials are materials that present properties contrary to most found in nature. For structural metamaterials the most extensively studied cases are those which exhibit negative Poisson's ratio (NPR) - auxetics - or negative thermal expansion coefficient (NTE).

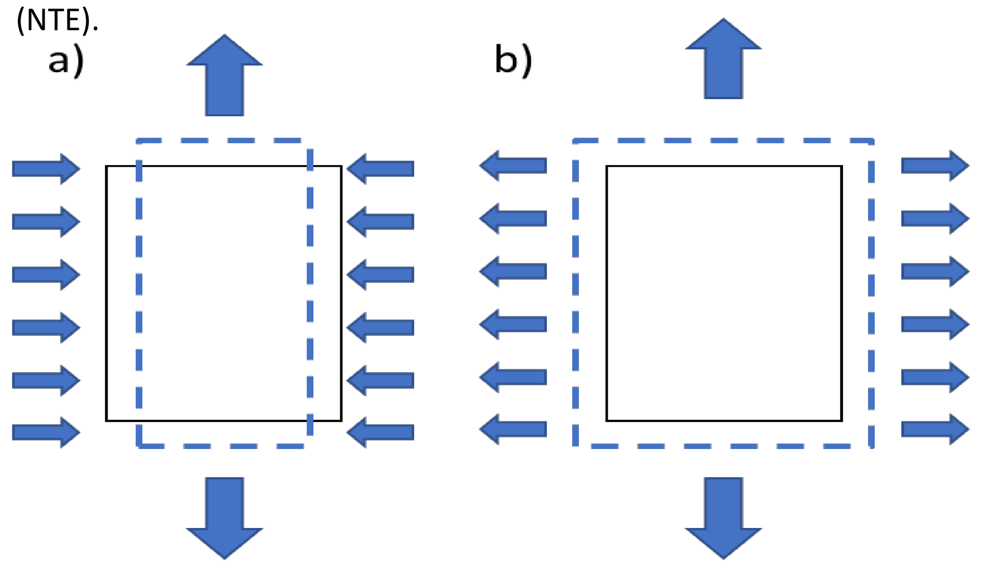

Image 1 – Difference in Poisson's ratio: a) Positive, b) Negative.

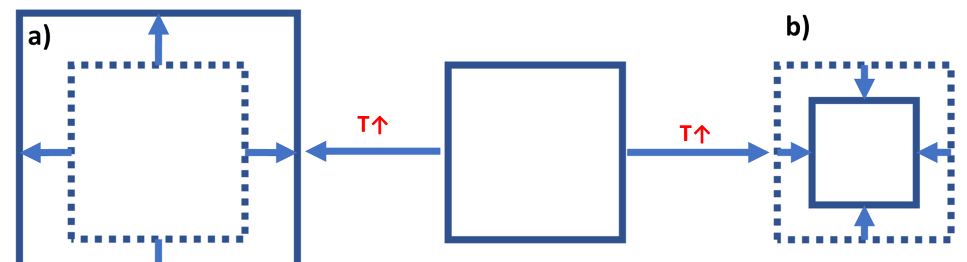

Image 2 – Difference in termal expansion coeffient: a) Positive, b) Negative.

These properties can be found in nature for very specific cases and conditions. Cork is known to have a Poisson's ratio of zero while re-entrant polymer foams and some metallic crystals have a Poisson's ratio below zero. Water is known to have a negative thermal expansion coefficient between the temperatures of 0 and 4 ºC, while ZrW2O8 is known to have a negative thermal expansion between the temperatures of 0.3 and 1050 Kelvin, among others.

Anepectic materials, on the other hand, which simultaneously present both NPR and NTE, while being potentially advantageous in fields as diverse as those of medicine, defense, sports, automobile, and aeronautics, , have only recently come to light and as such still warrant in depth studies. The anepectic behavior can be obtained by coupling two or more adequately chosen base materials with specific architectures.

By observing the three categories of known auxetic materials (re-entrant, chiral, and rotating), it is possible to pick which parts of a given structure must be substituted by a second material, of adequate stiffness and thermal expansion, to turn an auxetic material into an anepectic one. This approach was previously applied for 2D meshes (Raminhos, Borges, and Velhinho 2019), and current work aims at extending a similar result into the third dimension.

The present work reports a set of simulation and experimental results concerning both rotating and re-entrant 3D metamaterials produced by filament deposition methods. In the current literature 2D structures are rather common while 3D still has room for further research.

Double Ring

Picking up on L.Wang et al.'s work (Figure 3) we attempted two approches. First, confirm the structure's auxeticity and study possible configuration to best tailor this property, second, to introduce a second material and produce a 3D anepectic material.

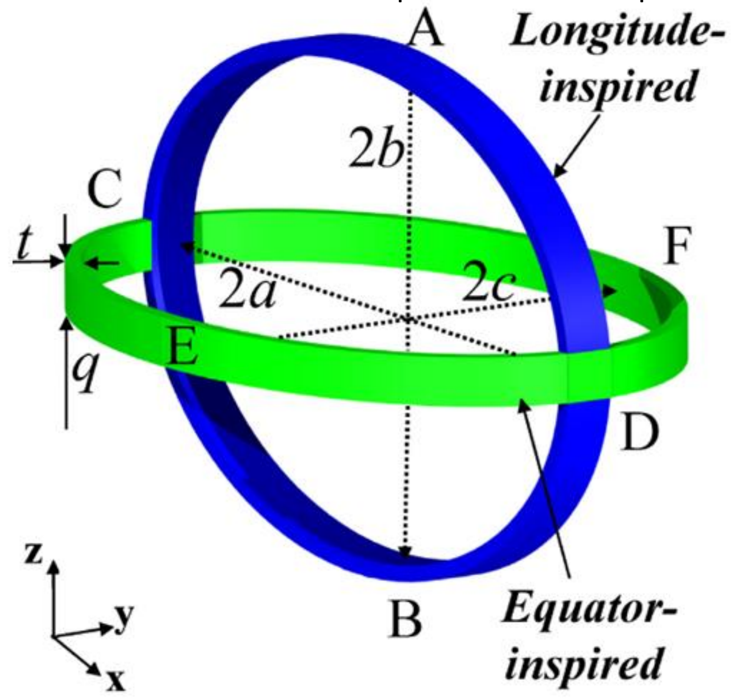

Figure 3 – Longitude/Latidude inspired auxetic structure. L Wang et al.

Four different structures (Figure 4) were simulated, aiming to mimick the mechanical properties of intervertebral disks. Along with studying different geometries, different ring thicknesses were considered and different stacking heights. In figure 5 we can observe the intended auxetic behavior.

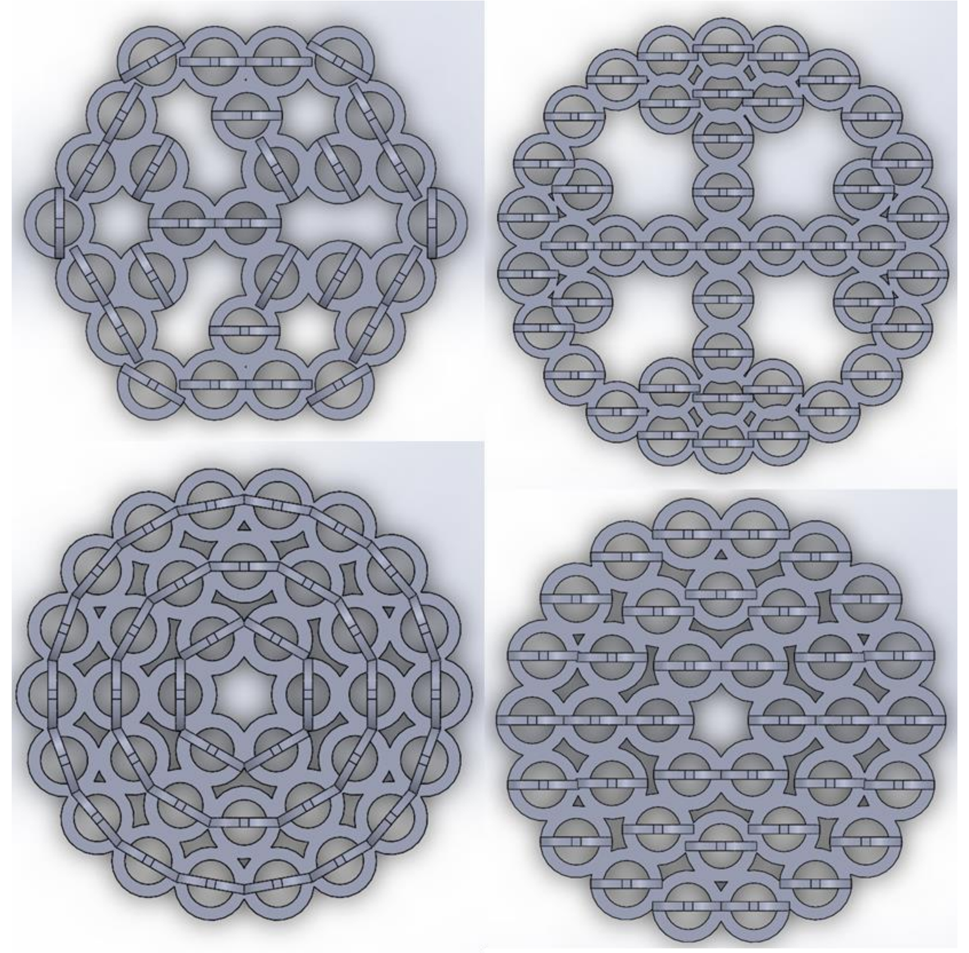

Figure 4 – Configurations considered.

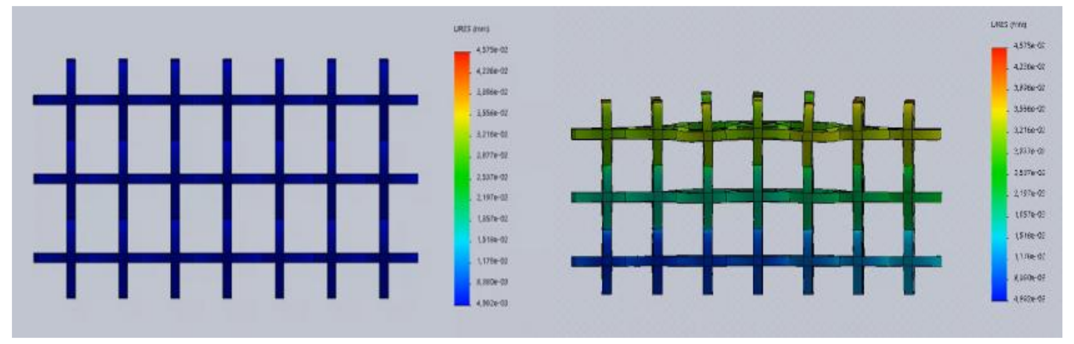

Figure 5 – Simulation results in SolidWorks, demonstrating auxetic behavior. This result was obtained for all the structures considered.

In the second approach we substituted part of the ring with a second material according to figure 6 and simulated several angles to best obtain a negative thermal expansion coefficient along one of the axis, making the structure anepectic; this is demonstrated by the simulation shown in figure 7.

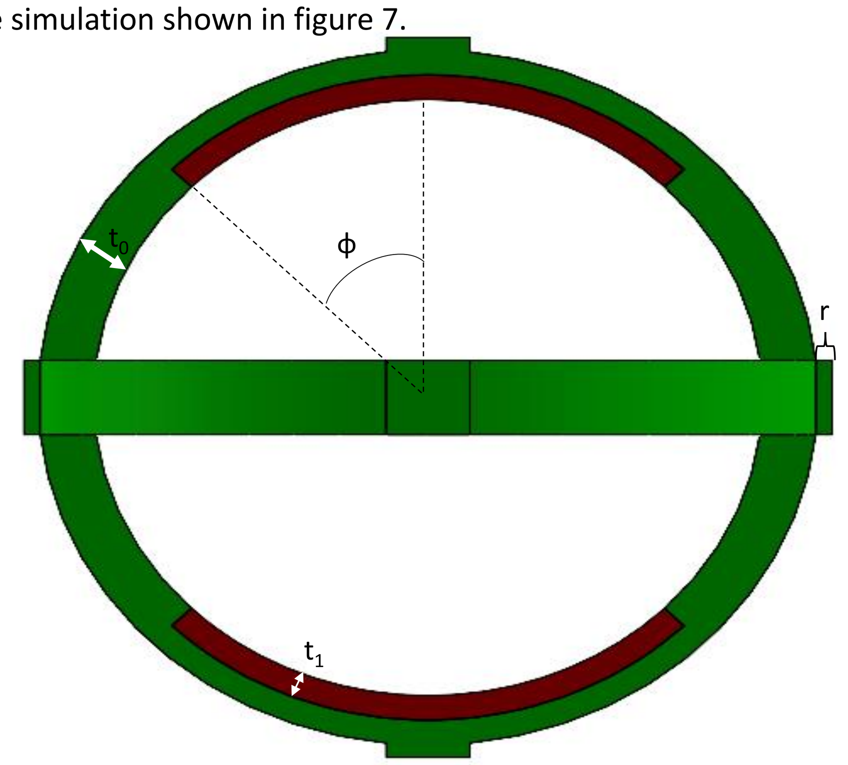

Figure 6 – Schematic of the four variables considered for simulation.

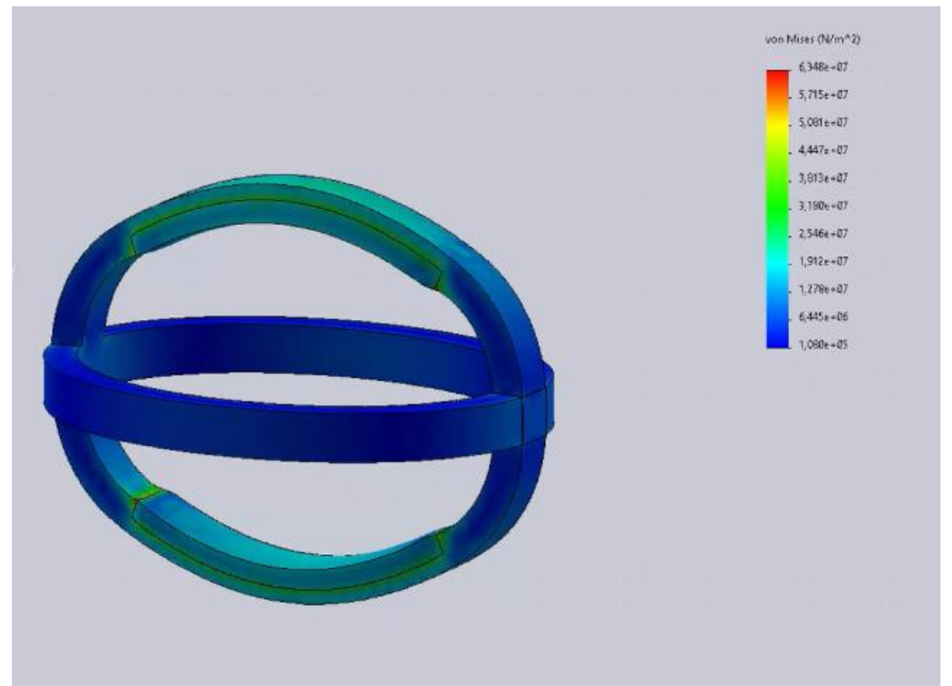

Figure 7 – Simulation demonstrating negative thermal expansion along one axis.

Gyroid

The gyroid structure is a minimal continuous surface with no symmetry nor straight lines, This geometry not only is easily manipulated but also displays a high strength to weight ratio. This structure present near zero Poisson's ratio for flexible materials (Figure 9).

The surface can be approximated by the following equation:

$$f = \sin x * \cos y + \sin y \cos z + \sin z \cos x$$

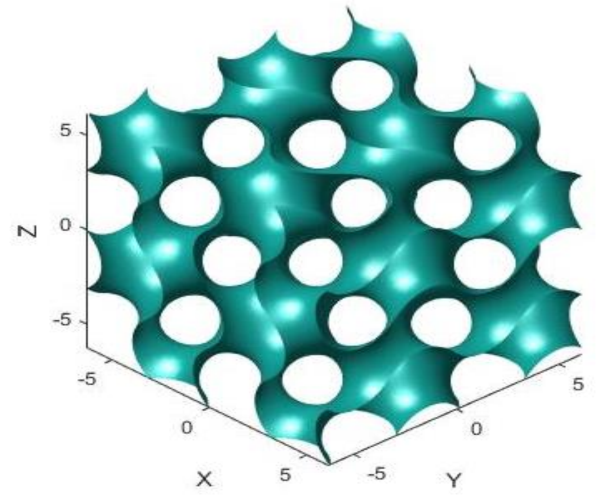

Figure 8 – MATLAB generated gyroid structure

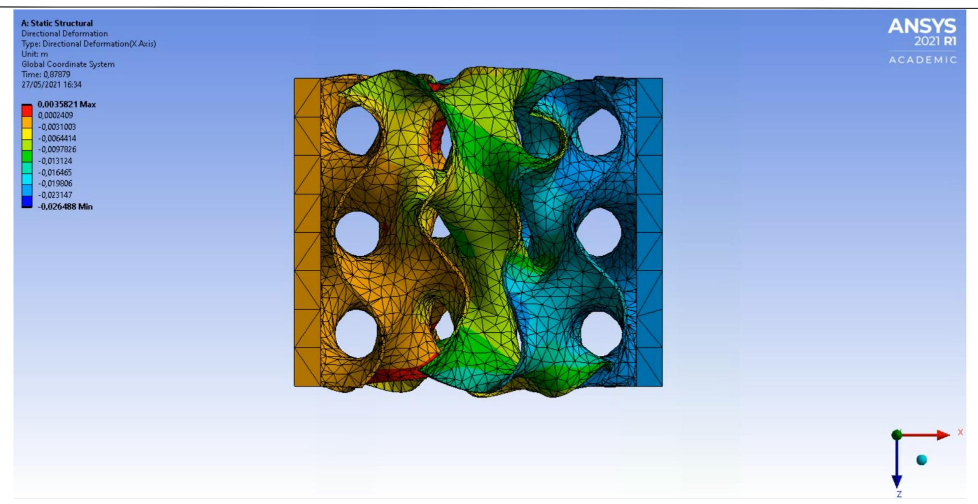

Figure 9 – Simulation result demonstrating near 0 Poisson's ratio.

By manipulating the equation to the following shape, we can introduce gradients to better mimic the mechanical properties of different bone structures, in this case a radial gradient as demonstrated in figure 10:

$$f = \sin x * \cos y + \sin y \cos z + \sin z \cos x - c * (x^2 + y^2)$$

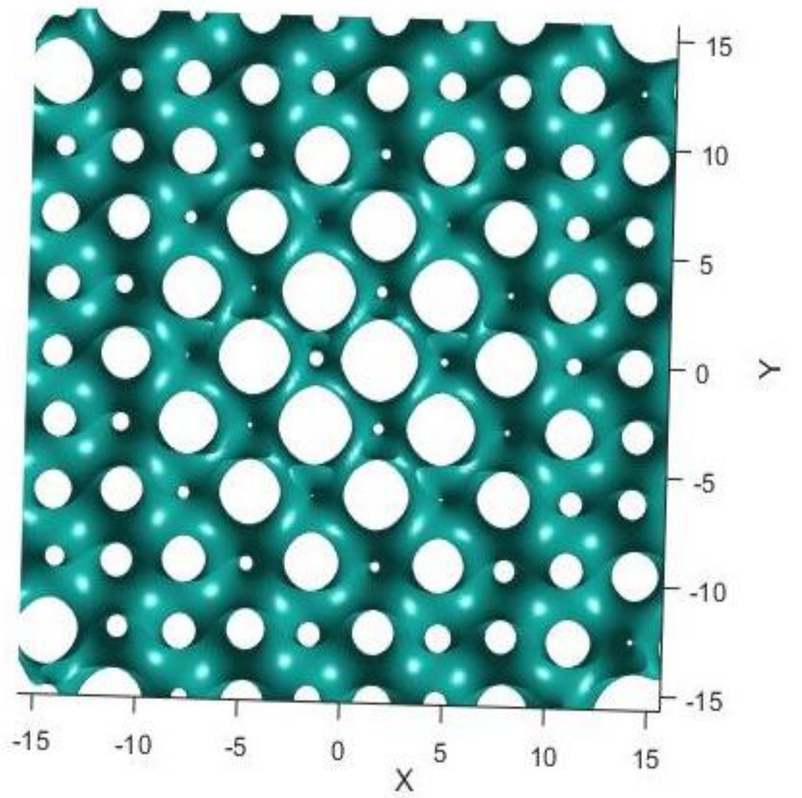

Figure 10 – Top view of a gyroid structure generated for c=0,006 demonstrating a radial gradient.

Experimental work has begone for the simulation validation as can be seen in figure 11.

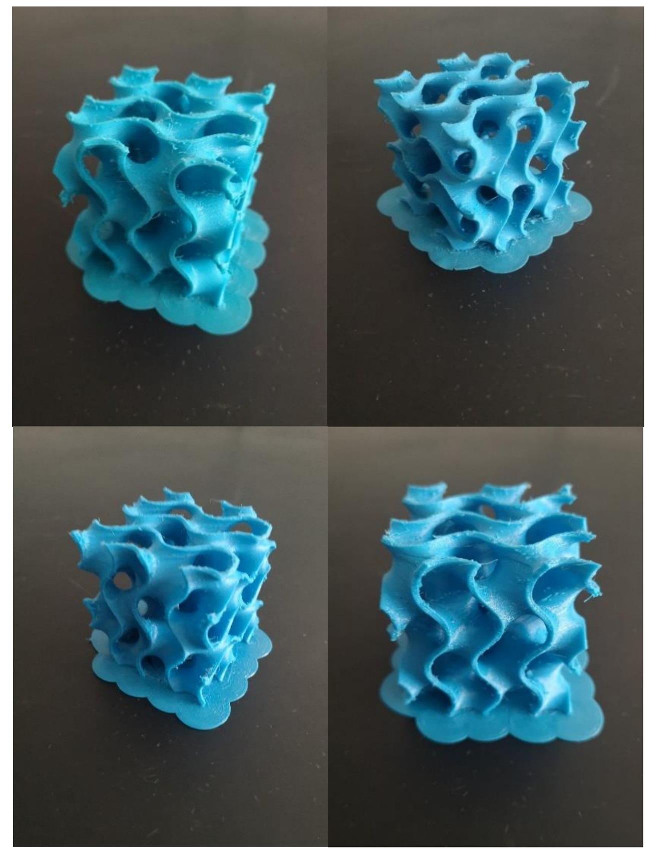

Figure 11 – Several printed gyroid structures.

Conclusion

We managed to obtain simulations demonstrating auxetic and anepectic behaviour for two different three-dimensional structures and are currently working on the validation phase and characterization.

Figure 12 – Production of the double-ring structure.

References

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Affiliations

a – CENIMAT/I3N, Materials Science Department, NOVA School of Science and Technology, Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal

b – UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal

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