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KIRIGAMI INSPIRED NATURAL FIBRE CELLULAR STRUCTURES FOR FUTURE VIBROACOUSTICS APPLICATIONS

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ABSTRACT

The Aerospace segment makes large use of cellular structures in sandwich panels, which are known to possess good stiffness while saving weight. Metallic cores are currently being replaced by different classes of composites, especially because of their poor vibration transmissibility. The inclusion of vibroacoustics constraints in the design process gives the opportunity to obtain multifunctional structures that still provide mechanical efficiency while introducing absorption, tunable vibration transmissibility or damping capabilities. In this work, natural fibre prepreps were turned into periodic panels to obtain cellular structures with improved damping properties, using the Japanese art technique of cutting and folding paper, known as Kirigami. Varying the geometric characteristics of the honeycomb, numerical simulations were carried out in order to identify the best performing candidate in terms of the above mentioned properties. Results show that hexagonal cell honeycombs have smaller values of transmissibility than the auxetic one.

1 INTRODUCTION

Periodic structures have been largely investigated for their in-plane vibroacoustics performances, starting from Brillouin initial studies on the subject [1]. Mead demonstrated [2] how periodical geometry and/or material discontinuities attenuate the propagation of in-plane waves through the structure, as a result of the interaction between incident, reflected and transmitted waves at the discontinuity points.

In this work, the out-of-plane vibration damping of Kirigami made honeycomb cores for future vibroacoustic purposes has been investigated.

The paper is organized as follows. In section 1 the Kirigami manufacturing process of the honeycombs is described. In section 2, the numerical simulations carried out so far are summarized. Details about the Finite Element model used for the simulations are given, followed by the results obtained from the transmissibility analysis. Finally, section 3 gives an outline of the main results of the work and of the future investigations.

2 KIRIGAMI MANUFACTURING

Kirigami is an ancient Japanese art of cutting and folding paper. The idea of engineering Kirigami was first explored by Nojima and Saito [3]; since then, the technique has been widely applied to both composite and thermoplastic materials [4] to form a 2D sheet material into a 3D cellular structure.

In this work, the material used to manufacture the honeycomb is natural-fibre prepreg - flax fibres with polypropylene matrix - characterized by 2x2 Twill weaving. Both hexagonal and auxetic cell honeycomb were produced. In order to obtain the final honeycomb 3D shape, the Kirigami manufacturing process consisted of three main steps:

1. **Corrugating + Thermoforming:** the sheet material was thermoformed between hexagonal tooling in a hot press for 20 minutes, at a temperature of 170° C and a pressure of 10 GPa. The hexagonal and auxetic shapes were here obtained using the same mould, but folding the sheet on the hexagonal tooling in different ways.
2. **Cutting:** a pattern of slits was laser cut into the corrugated material. The result for the hexagonal cell honeycomb is shown in Figure 1 (picture on the left).



Figure 1. Hexagonal cell honeycomb: corrugated sheet after the thermoforming and laser cutting of the slits (left) and after folding along the slits (right).

3. **Folding:** the corrugated sheet was folded repeatedly back on itself such that the semi-hexagonal slits opened up into hexagonal holes. The result was an open honeycomb (Figure 1, picture on the right). Finally, the adjacent cells were bonded together to form a prismatic hexagonal structure by means of a bi-component epoxy resin adhesive. In Figure 2 both the hexagonal and auxetic cell honeycombs are shown.



Figure 2. Hexagonal cell honeycomb (left) and re-entrant (auxetic) cell honeycomb (right) resulting from the Kirigami manufacturing.

3 NUMERICAL SIMULATIONS

A finite element model was developed in order to simulate a shaking table test. In the test, the honeycomb is placed on the shaking table with a mass on the top of it. The mass has the double function of shifting its characteristic frequencies towards lower values and assuring uniform displacements at the top. Transmissibility will be calculated from the ratio of out-of-plane acceleration measured both on the upper surface of the mass and on the shaking table.

From a numerical point of view, since in the Fourier domain the ratio of accelerations is equal to the ratio of displacements, an harmonic analysis was carried out to calculate the displacements, and so the transmissibility.

3.1 Finite Element model

ANSYS® Mechanical APDL 15.0 was used for the Finite Element modelling and the harmonic analyses. On the other hand, MATLAB® provided an interactive development environment to perform data analysis and visualization, numerical computation and algorithm development. In terms of the FE modelling, the material and geometric properties of the auxetic and hexagonal cell honeycombs are shown in Figure 3. Moreover, damping was assumed to be 4%.

Shell elements (SHELL181, element size = 1.5 mm) were used throughout the models. In

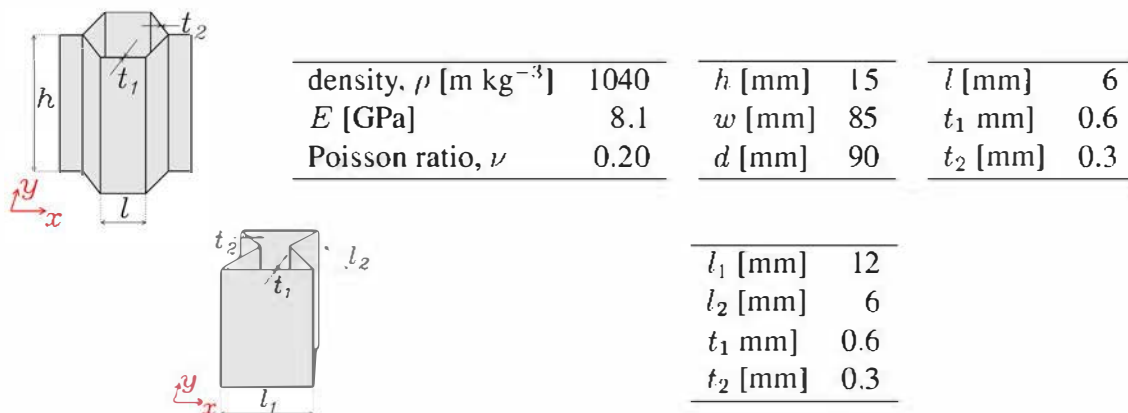


Figure 3. Hexagonal cell - From the left: characteristics of the material; honeycomb dimensions; geometric characteristics of the cell. w = length in x direction, d = length in y direction. auxetic cell - Geometric characteristics

order to simulate the shaking test configuration, the in-plane displacements and out-of-plane rotations at the base of the honeycomb were blocked. The shaking table motion was reproduced by applying uniform out-of-plane displacements at the base. Furthermore, the mass on the top of the honeycomb was simulated by assigning a MASS21 element to a reference node, which was then linked to all the nodes of the honeycomb's top face in order to obtain a uniform distribution.

3.2 Transmissibility analyses

The harmonic analysis was carried out in the frequency range [10, 4000] Hz, with a step of 10 Hz. The output displacements were used to calculate the *transmissibility*, as the ratio of out-of-plane displacements on the upper surface of the mass and on the honeycomb's base.

For both the hexagonal and the auxetic configurations, a *parametric* study was carried out by either varying the honeycomb height or the top mass. In particular, varying the height, the mass is kept constant and equal to 1.5 kg, while as the mass changes the height is 15 mm. Figure 4 shows the transmissibility curves for the hexagonal cell honeycomb in function of its height. In Figure 5, the graphs show the peaks of transmissibility for both hexagonal and auxetic configurations and for both parametric studies.

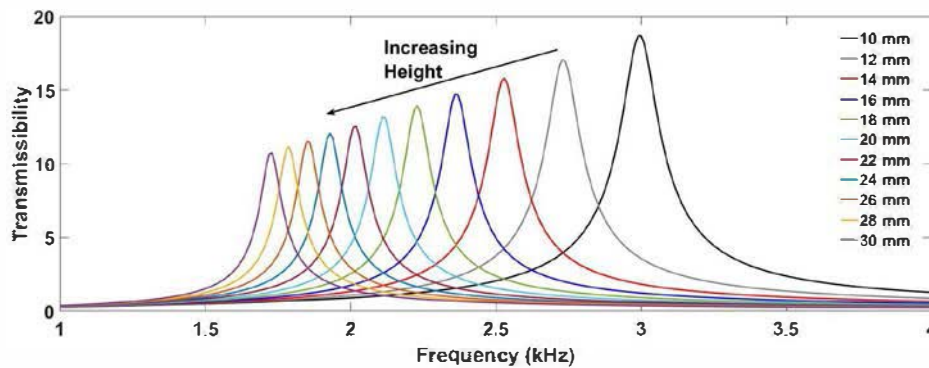


Figure 4. Hexagonal cell honeycomb - Transmissibility curve for variable top mass values.

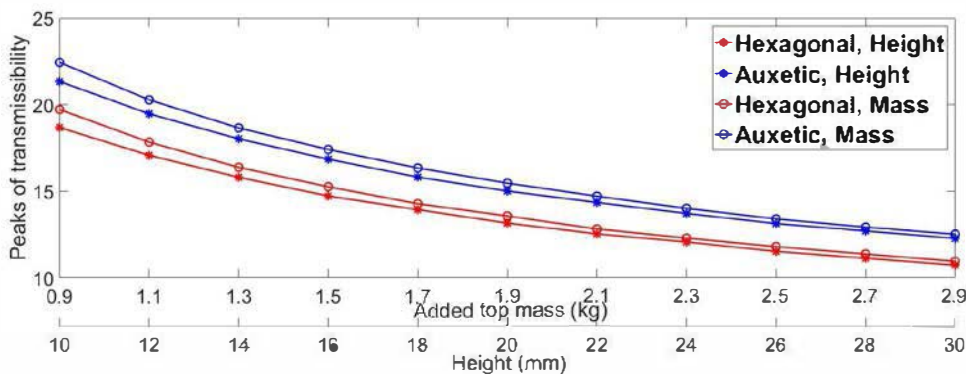


Figure 5. Transmissibility peak values for hexagonal and auxetic configuration in function of the height of the honeycomb itself and the mass added on the top.

4 CONCLUSIONS

The results of the numerical parametric study show how, for both the auxetic and hexagonal configurations, the peak of transmissibility decreases as either the height of the honeycomb or the mass applied on the top of it increase. Furthermore, among the two configurations, the hexagonal shows better absorption properties than the auxetic one, as the peaks of transmissibility have larger values for the latter. Future developments will be carrying out the shaking table test on the various configurations that were analyzed in this paper in order to compare numerical and experimental results, and a Dynamic Mechanical Analysis characterization of the material in order to verify the value for the damping. Finally, in-plane vibroacoustic properties of the honeycomb cores will be investigated.

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