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CELLULAR CORES WITH NEGATIVE POISSON’S RATIO FOR SANDWICH PANELS

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Abstract. *Sandwich structures have been intensively studied since their first extensive use in the Second World War. The major interest of researchers nowadays is to develop high-performance cellular cores while lowering the production costs, and by this, launching the sandwich panels into a wide range of industrial applications. A particular category of such cores are the structures with negative Poisson’s ratio (NPRs). Taking into account the existing structures developed up to the present, the main objective of this paper is to present a consistent study on this issue and to investigate the transition process of a structure from positive to negative Poisson’s ratio.*

Keywords: *Sandwich panels, cellular cores, negative Poisson’s ratio.*

1. Introduction

A sandwich panel is defined as a special laminated composite, manufactured from different materials bonded to each other, in order to use their mechanical properties as an advantage for the whole assembly. Its construction contains two thin, stiff and strong faces, both of them bonded through different procedures (adhesive, brazing etc.) to each sides of a thick layer called core, Figure 1. The resulting structure has significant advantages, such as: high stiffness and strength to low weight ratios, good thermal and acoustic insulation, high energy absorptions capacities etc. [15].

Fig. 1. *Transverse section of a sandwich panel*

The topology of cellular structures used as cores for sandwich panels is various throughout their development, for example: balsa wood, cellular foams, honeycomb and corrugated [15].

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2. Types of Corrugated Structures Used in Manufacturing Sandwich Panels (Classification with Respect to the Poisson's Ratio)

Research in this area states that corrugation could give the possibility to obtain highly directional mechanical properties and provide high stiffness for sandwich panels, which can speed up the process of implementing their use in industries like aircraft, naval and even automotive [4-9]. The core structures obtained through a corrugation process can have several types of geometry such as: triangular, trapezoidal, sinusoidal, cellular etc. [1].

One of the most important characteristics of cellular structures is relative density (ρ_r) which allows to evaluate the lightweight characteristic of a newly developed periodic cell [13]. Apart from the elastic moduli and ultimate strength, another important characteristic that contributes to evaluating the behaviour of a sandwich panel is the Poisson's ratio, defined as the transverse strain divided by the axial strain. In other words, the Poisson's effect is recorded when a material is compressed in one direction and it tends to expand in the perpendicular direction. A classification of cellular structures with regard to Poisson's ratio is presented in the following paragraphs.

2.1. Positive Poisson's Ratio (PPR)

Poisson's ratio for most of the categories of solids has positive values usually in the range of 0.25-0.33 [1].

Most of the mechanically expanded structures are included in the category mentioned above, as shown in Figure 2. They are manufactured from continuous metal sheets, previously cut and perforated after a given pattern, forming an open cell structure [11].

These type of products have gained popularity in the last few years because they offer competitive compression and bending properties, comparable to the existing honeycombs [5], as well as a reduced manufacturing costs and high percentage of raw material usage [7].

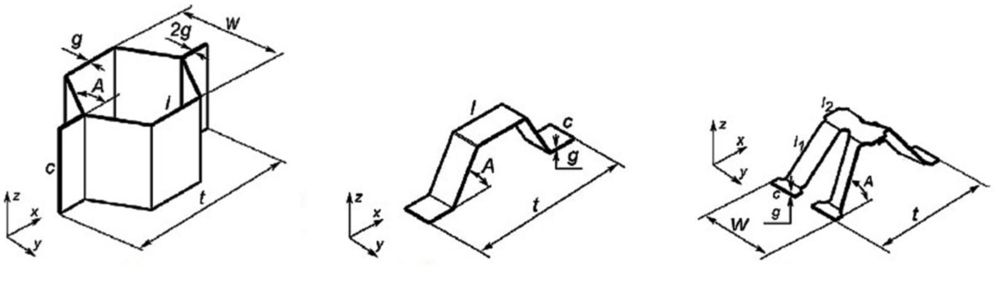

Fig. 2. *Example of corrugated topologies with positive Poisson's ratio* [11]

2.2. Zero Poisson's Ratio (ZPR)

Structures with zero Poisson's ratio are those types of solids which if compressed, on their geometry would not undergo any expansion in the perpendicular direction, and vice-versa.

A cellular structure with varying behaviour is the honeycomb. Current research describes another type of structure with zero Poisson's ratio, consisting in an optimized honeycomb. In this case, the resulting cell has the advantage of having high bending compliance at large strains, and therefore, the structure may be used in cylindrical sandwich panels' applications, Figure 3 [3].

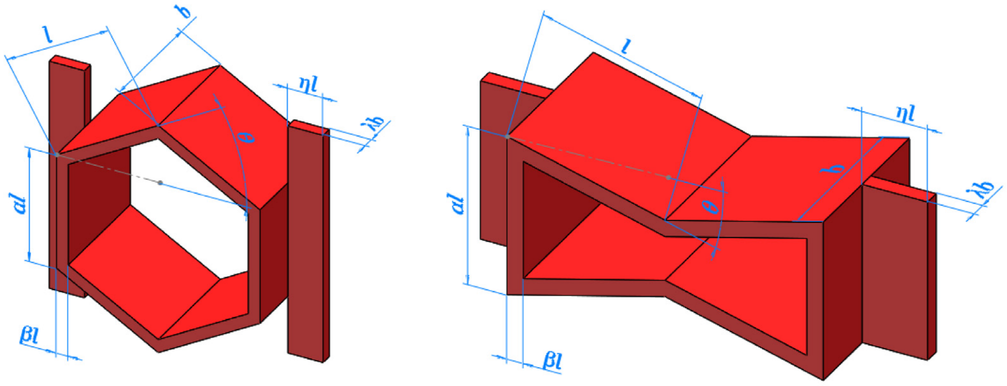

Fig. 3. *Example of optimized honeycomb structure with zero Poisson's ratio* [3]

2.3. Negative Poisson's Ratio (NPR)

Structures with negative Poisson's ratios are those types of structures having the property to expand laterally when subjected to longitudinal extension strain and transverse contraction strain [13]. According to the research in the field, due to the large volume fraction of voids in the geometry of the honeycombs, they offer enhanced flexibility when subjected to large strain, which can be considered as an advantage and exploited in future studies [2-10].

There is consistent research in the field of NPR structures, strictly regarding the optimization of the existing honeycomb shape, in the attempt of obtaining structures with special functions [8]. Due to these optimizations, the resulting geometries can lower the Poisson's ratio up to -1.05, as well as present higher stiffness if an accurate optimization of the parameters is to be performed [6-8].

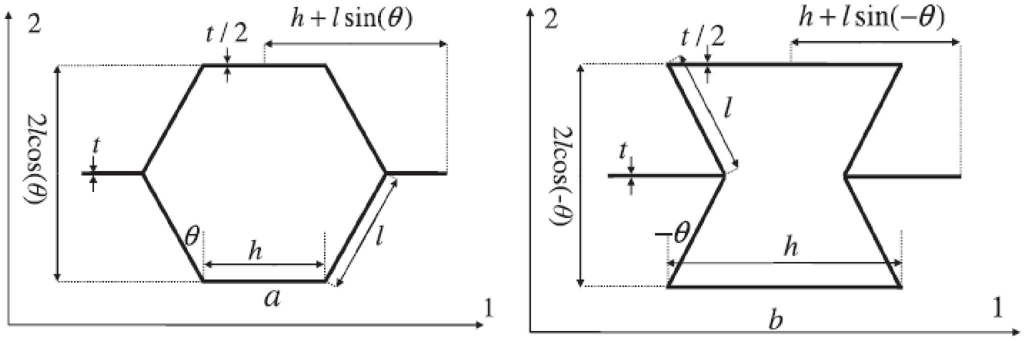

Fig. 4. *Optimized structure with negative Poisson's ratio* [8]

The structure presented in Figure 4 has negative Poisson's ratio when the length of the rib is modified, and in this case, the Young's modulus is enhanced.

3. The ExpaAsym Structure

ExpaAsym structure is a periodic cellular core developed at Transilvania University of Brasov, obtained through a mechanical expansion process, from a previously cut and perforated sheet metal, conducted after an established pattern [14]. The bonding surface is created by bending the area generated between the perforations, by the cut, at a desired angle, previously calculated, and both of the resulting shoulders can be bent in the same way or contrary. The expansion is exerted by applying a force F on the plane of the sheet metal, perpendicular to the direction of the perforations, while on the opposite side, the semi-finished product is fixed, resulting the expanded cellular structure, Figure 5.

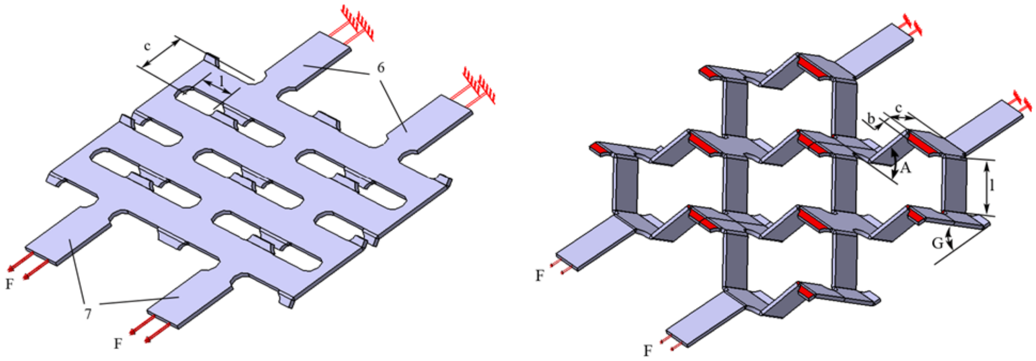

Fig. 5. *The ExpaAsym structure, before and after the expansion process* [11]

The expanded periodic structure is defined by several main parameters: internal angle (*A*); width of the perforation (*2b*); distance between two transversal cuts (*c*); length of the cell's lever arm (*l*). These parameters help in defining the expansion angle, in order to determine the bulk dimensions of the unit cell, using the following formulae:

$$G = \tan^{-1}\left(\frac{l\sin(A)}{c}\right), \qquad (1)$$

$$w = 2l(1+\cos(A)), \qquad (4)$$

$$h = 2(c-b)\sin(G), \qquad (2)$$

$$\rho_r = \frac{\rho}{\rho_s} = \frac{g}{(1+\cos(A))l\sin(A)}. \qquad (5)$$

$$t = \frac{2c}{\cos(G)}, \qquad (3)$$

The structure was studied regarding several interdependencies between the parameters mentioned above, but the one connection which has an influence directly on the geometry of the unit cell, is the relation between the internal angle (*A*) and the expansion one (*G*) [13].

Taking into account the *l/c* ratio, and varying it in several combinations, the author has shown the interdependency between the internal angle, with a variation in the range 5°-120°, and the expansion angle, Figure 5.

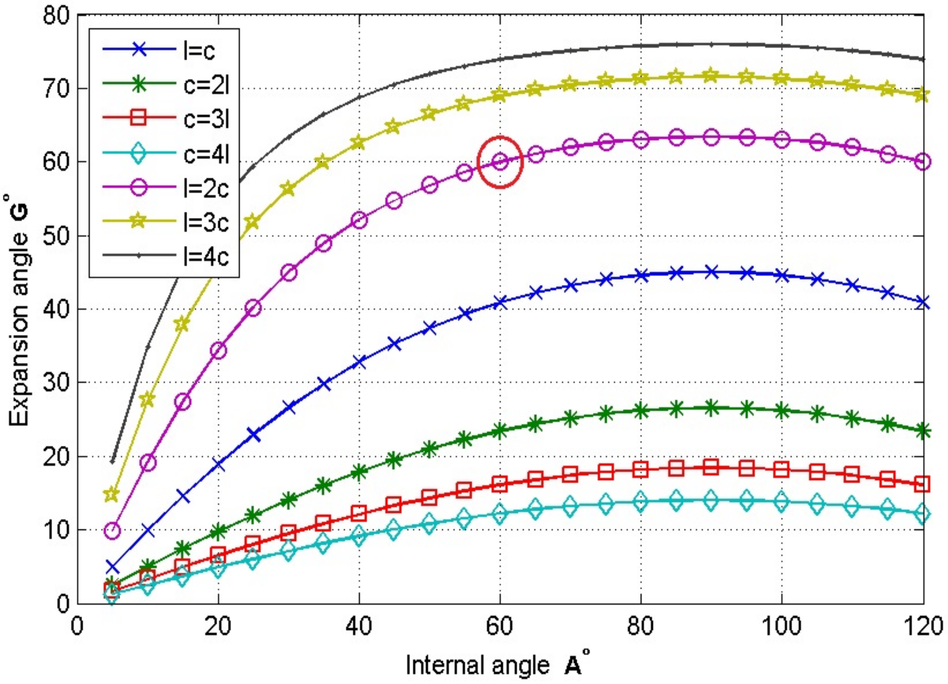

Fig. 6. *The interdependence between the internal and expansion angle* [14]

From the graph in Figure 6, it can be concluded that, in one of the cases analysed, when *l=2c* and the internal angle equals 60°, the value of the expansion angle is equal with the one of A, and thus, the geometry of the unit cell becomes hexagonal. This study has conducted to the possibility that, if the internal angle is to exceed 90°, the geometry of the structure can reverse, and turn into a specific auxetic one (with negative Poisson's ratio).

4. Conclusions

Due to its high performances, the honeycomb structure still remains, up to the present, one of the most popular structures used as core for sandwich panels. Due to the extensive research performed in the direction of NPR structures, it has been proven that auxetic honeycombs have quite a good perspective for the future, since there is registered a significant enhancement of the Young's modulus.

The ExpaAsym structure offers great possibilities due to the flexible topology of its cellular core; future research may be conducted to prove that the structure can have a negative Poisson's ratio, which could give the structure higher mechanical properties. The advantage of this particular structure is related to its significant bonding surface, which could ease the technological flow, and, by this, lower the production costs. If it will be proven that the structure is indeed auxetic, together with improved mechanical properties, this type of core could upgrade the functionality of the sandwich panel, as well as extend its use in different existing industries. In this respect, the analytical and numerical investigation of its Poisson's ratio represents a future research direction to be exploited and a challenging objective for structural development and optimization.

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