Topologic Study of a Novel Periodic Cellular Core for Sandwich Panels

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Abstract. The use of sandwich panels in industries such as aerospace, naval and automotive is extending nowadays, due to their high mechanical performances with respect to low-weight ratios. In this regard, the concept of ‘lightweight structures’ has been already acknowledged as the alternative solution in addressing one of the major issues when it comes to the future vehicle design and construction. This paper aims to present a novel cellular structure used as core in sandwich structures, obtained through a mechanical expansion process. A topological study is carried out, proving the competitive relative density of this new structure compared to the already existing ones.

1. Introduction

The sandwich structures have been intensively studied within the last decades, being considered as alternative solution to traditional materials in various applications that require minimal mass while maintaining high stiffness and strength. Nowadays a considerable number of solutions is offered when it comes to material use and architecture of the core [1].

This has powered the use of sandwich panels not only in the aircraft industry, but as well in the naval, railway, civil and also automotive industries [2]. The latter has started to consider using lightweight structures when the vehicle’s weight begun to be an issue (i.e. in order to comply to the strict environmental regulations and standards, which require manufacturers to decrease the levels of fuel consumption and gas emissions) [3]. Moreover, the attempts to develop and extensively use of the electric vehicles has constantly stimulated researchers to identify new alternatives to replace the traditional materials.

The essential part of any sandwich assembly is represented by the cellular core, which has to meet two main requirements: first of all, from a structural point of view, the role of the core is to maintain constant the distance between the lateral sheets and to stabilize them in such a manner to prevent local buckling; secondly, a low density is required together with a high shearing and bending stiffness and strength on different directions [2].

Although the honeycomb represents the best solution for the cellular core due to its good mechanical properties, its high production costs is still a big disadvantage that prevents its use at a very large scale.

Consequently, significant research in the area of lightweight cellular structures has been carried out resulting different periodical topologies such as: sinusoidal, triangular, trapezoidal, corrugated etc. These newly developed cellular topologies are intended to offer multi-functionality to the sandwich structure due to a set of essential mechanical properties such as: low relative densities, high
compressive, bending and shearing stiffness together with a significant reduction of manufacturing costs [4].

Research conducted at the Transilvania University of Brașov resulted in designing a periodic cellular structure, ExpaAsym, easy to manufacture and at a significantly reduced price compared to the honeycomb. Although it has proven to have a lower relative density and comparable mechanical properties [5], the low bonding surface raises some problems when sandwich panels are constructed using ExpaAsym as a core [6].

This paper aims to present a novel cellular structure obtained through the same manufacturing process as ExpaAsym (i.e. mechanical expansion) but offering a considerably higher bonding surface. A topologic study is carried out, proving the competitive relative density of this new structure compared to the already existing ones.

2. The novel cellular core

The two core structures designed as alternatives to other corrugated cores used for sandwich panels are presented in figure 1: a) – ExpaAsym, which has been already validated through analytical and experimental studies [5, 6] and b) – the novel core structure, still under development but considered an interesting alternative for overpassing the bonding issues identified at ExpaAsym. The novel cellular structure has been developed taking into consideration the advantages offered by the lattice truss architectures (load-bearing abilities, energy absorption capacities etc. [4, 7]) and its topological study is to be presented in the following paragraphs.

![Figure 1. Cellular core structures proposed for sandwich panels: a) ExpaAsym b) novel cellular core.](image)

The manufacturing technology for this type of corrugated core is relatively simple. On a single metallic sheet, a pattern of cuts and perforations is performed. A series of bend lines is subsequently applied, at an internal angle ($\alpha$), in order to have a full control on the mechanical expansion process. The resulting metal sheet is afterwards expanded at a specific angle ($\beta$), by applying a force along a direction perpendicular to the pattern of cuts while the opposite edges are kept fixed along the direction of the applied force, thus resulting the expanded unit cell, figure 2.
Figure 2. The novel cellular core.

The geometry of the expanded cellular structure is defined by the following parameters: internal angle \( A \); expansion angle \( B \); length of the arm’s base \( c \); length of the cell’s arm \( l \), radius of the perforation \( r \), distance between two perforations \( l_1 \), thickness of the base material \( g \), length of the unit cell \( w \); width of the unit cell \( t \), height of the unit cell \( h \), figure 2.

In regard to the parameters afore mentioned, the gauge dimensions \( h, t, w \) can be defined with the help of the equations below:

\[
w = 2l_1 + 2l \cos(B) + c \tan(A) + 2R
\]

\[
t = 2c + z + 2 \left[ l^2 \cos(B)^2 - \left( l \cos(B) - R + 2g + \frac{c \tan(A)}{2} \right)^2 \right]^{1/2}
\]

\[
h = g + l \sin(B)
\]

3. Relative density of periodic cellular structures

The parameter that offers the possibility to evaluate the lightweight characteristic of corrugated cores is the relative density \( \rho_r \), which is represented by the ratio between the volume of base material from which the cellular core is manufactured, and the resulting volume of the generated structure [8].

\[
\rho_r = \frac{v_m}{v_s}
\]

3.1. Study upon the relative density of existing topologies

In order to determine the performance of the newly developed cellular structure, a study between the most common topologies used in design and construction of sandwich panels has been carried out. In this regard, four topologies have been taken into consideration, for which the relative density has already been determined in the literature [9, 10]: triangular, trapezoidal, honeycomb and ExpaAsym.
Figure 3. Main core topologies for sandwich panel construction: a) triangular cores, b) trapezoidal cores, c) honeycomb cores.

For triangular cores, figure 3a), the relative density can be defined as [9]:

\[ \rho_r = \frac{2}{\sin(2B)} \frac{g}{l} \]  

(5)

In the case of trapezoidal cores, Fig. 3b), the relative density can be determined as [10]:

\[ \rho_r = \frac{g(2l + 2l_1)}{(2l_1 + 2l \cos(B))(g + l \sin(B))} \]  

(6)

For honeycomb cores, Fig. 3c), the relative density can be defined as [10]:

\[ \rho_r = \frac{2g(2l + 2l_1)}{(2l_1 + 2l \cos(B))(2g + 2l \sin(A))} \]  

(7)

For the ExpAsym structure, the relative density can be determined using the following formula [2, 6]:

\[ \rho_r = \frac{g}{(1 + \cos(A))\sin(A)} \]  

(8)

Although the ExpAsym structure represents a competitive solution from the relative density point of view, there is still an aspect which requires further attention – the relatively low bonding surface still rises some problems when sandwich panels are constructed using this topology as a core, due to the complexity of assembling the lateral faces [6].

3.2. The relative density of the novel cellular core

By analysing the topology of the newly developed structure we can conclude that the value of the internal angle \( A \) depends on the value of the radius of the perforation \( R \) and the length of the arm’s base, using the formula below:

\[ A = \arctan\left(\frac{2R}{c}\right) \]  

(9)

Using the formulae for the gauge dimensions, the relative density of the novel cellular core can be determined as follows:

\[ \rho_r = \frac{4cg(l + l_1 + 2R) - bgl_1 - 8glr - 4\pi gR^2}{wth} \]  

(10)
For a better understanding of the structure’s behaviour, tri-dimensional cases were taken into consideration. Each of them contains a set of fixed parameters (l1=10 mm, g=0.3 mm and c=15 mm) and a set of variables: the radii of the perforations (3, 4 and 5 mm) and the length of the cell’s arm, in the form of three ratios, \( l=c, l=2c, l=3c \).

As previously shown in eq. (6), (7) and (8), the gauge dimensions are depending on the value of the expansion angle \( B \). Taking this into consideration, an essential aspect is the influence the latter has on the relative density of the core, the results being shown in the graph in figure 4.

![Figure 4. The dependency between the expansion angle and the relative density of a unit cell](image)

This graph shows the dependency between the expansion angle and the relative density of a single unit cell. The value for the relative density decreases when increasing the expansion angle.

In order to highlight the advantages of the newly developed cellular structure, compared to the ones mentioned above (triangular, trapezoidal, honeycomb, ExpAAsym), the relative density has been determined for a single unit cell, while maintaining several relations between the established parameters. The length of the cell’s arm \( l \) has been kept the same for all the types of structures mentioned above \( l=15 \text{ mm}, 30 \text{ mm and } 45 \text{ mm} \). The value for the expansion angle has varied in the interval \([0°-120°]\) according to how permissive the topology is, while the width \( t \) and the height \( h \) have been determined according to the length \( w \) as follows: \( t=w/2 \) for triangular and trapezoidal cores and \( h=w/2 \) for the honeycomb.
Figure 5. The dependency between the expansion angle and the relative density for the studied topologies.

The results are shown in the graph in figure 5, where: NC - novel cellular core, TriC – triangular cellular core, TrapC – trapezoidal cellular core, HonC – honeycomb cellular core, ExpaC – ExpaAsym cellular core.

4. Discussions

The values for the relative density for the cellular cores mentioned above have been obtained with the use of eq. (4). The common parameter for all the geometries taken into consideration within this study was considered the length of the cell’s lever arm (l), which has resulted in three dimensional cases: l=15 mm, 30 mm and 45 mm.

As it can be easily observed in the graph in figure 5, the relative density has a similar flow for all the studied topologies, in all of the established geometric cases; it decreases when increasing the expansion angle; reaching minimal values in the range [30°-70°], figure 6. Another important aspect worth outlined is that the relative density decreases when increasing the length of the cell’s lever arm, due to its direct proportionality with the volume of void in the cellular structure. Thus, the maximum values have been obtained when l=15 mm, while the minimum ones were encountered when l=45 mm.

For the triangular topology, the variation of the relative density has values in the range [0.01-0.06], while for the trapezoidal structure, the relative densities are set [0.01-0.04], with the advantage that the latter offers a significant bonding surface, which could deliver a cost efficient manufacturing process.

Compared to the other two structures mentioned above, the relative density for the honeycomb cellular core has the same evolution, with identical values as for the trapezoidal, in the given range of [0.01-0.04]. It represents closed topology consisting in two trapezoidal structures bonded to each other, but it also requires a double quantity of base material for creating a single unit cell than the latter. Together with a complex three-dimensional geometry, a time consuming manufacturing technology and a bonding surface equal to the thickness of the base material, the resulting production
costs are still extremely high even with nowadays technology. Despite this main disadvantage, it is successfully used in a large number of applications due to its high mechanical properties (strength and stiffness).

The ExpaAsym cellular core was designed to account for this specific disadvantage offered by the honeycomb and as shown in figure 6, its relative density has been reduced by half, due to its complex, yet easy obtainable topology, with values between 0.005-0.002. In the case of an expansion angle equal to 60°, the result is a honeycomb-like structure, which offers the advantages of reducing the material use by 50%, while providing a consistent bonding surface as opposed to the honeycomb. Besides these two main benefits, it is also significantly easier to manufacture by mechanical expansion, and thus it represents a potentially less expensive solution.

In the case of the newly developed cellular structure, the relative density is comparable with the one of the ExpaAsym, and varies in the range of 0.008-0.03. Having a similar manufacturing process, the main advantage offered by this topology is the consistent bonding surface it provides. This is an important issue to take into consideration when manufacturing sandwich panels, since it can simplify the assembling process and significantly reduce its production costs.

The mechanical expansion of the structure is being exerted on all three dimensions (directed by a set of bending lines at an internal angle \( A \)) thus; it provides a stable structure, which could lead in producing a substantially wider area of sandwich core using the same amount of base material.

**Figure 6.** Relative densities for the studied cellular structures in the interval [30°-70°].
5. Conclusions
The presented novel cellular core has been developed in order to keep up with the demands on the nowadays market and the main purpose of this paper was to perform an initial evaluation of its performance.

In order to achieve this goal, relative density has been taken into consideration as being the most important parameter when it comes to evaluating the lightweight capacity of cellular cores used in sandwich panel construction.

In this regard, a comparison between the relative densities of the novel core has been performed, as opposed to the ones of four existing cellular structures from the literature, only to conclude that it represents a promising solution for this industry.

The main advantages offered by this new design are consisting in a low relative density of the core, a significant bonding surface and a reduction in usage of base material. Together with a simple manufacturing method, they represent an important set of assets in the attempt in making a difference in designing lightweight structures.

A further objective of this research is to analyse the novel cellular structure's strength and stiffness in different mechanical load scenarios and to optimize its topology in order to obtain the highest mechanical properties.

6. References
[1] Zenkert 2009 *An introduction to sandwich structures* Student edition chapter 1 pp 1.1-1.4
[2] Velea M N 2011 *Lightweight cellular structures – Design, Modeling and Analysis* ed Universității Transilvania din Brașov (Brașov) pp 12-13
[3] Worldwide Emission Standards Passenger cars and light duty 2016-2017 *Delphi Innovation for the new world*
[4] Zhunli Tan, Lishuo Bai, Bingzhe Bai, Bing Zhao, Zhiqiang Li and Hongliang Hou 2016 *Materials and Design* 92 724–730
[5] Velea M N and Lache S 2011 *Mechanics of Materials* 43 377-388
[6] Velea M N, Wennhage P and Lache S 2012 *Materials and Design* 36 679-686
[7] Li-Jia Feng, Jian Xiong, Li-Hong, Yang Guo-Cai, Yu Wen Yang and Lin-Zhi Wu 2017 *Int. Journal of Mechanical Sciences* 134 589–598
[8] Wentao H, Jingxi Liu, Bo Tao, De Xie, Jiayi Liu and Min Zhang 2016 *Composite Structures* 158 30–43
[9] Biagi R and Bart-Smith H 2012 *Int. Journal of Solids and Structures* 49 3901–14
[10] Velea M N and Lache S 2009 *Proc. Engineering* 10 287–292