INVESTIGATION OF THE COMPRESSIVE BEHAVIOUR OF AN EXPANDED CELLULAR CORE

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Abstract: *The compressive behaviour of an expanded periodic cellular core, developed at Transilvania University of Braşov, is investigated by finite element analysis using a measured material response of an annealed stainless steel type 304. The ways in which the deformations modes in compressive loading are influenced by the geometrical parameters of the core are identified and discussed in this paper. The strength and normal compressive modulus of the core are evaluated in terms of the topology of the cellular structure. The values of geometrical parameters of the expanded cellular structure that offer the best compressive strength are identified.*

Key words: *sandwich structure, cellular core, numerical simulation.*

1. Introduction

Periodic cellular arhitectures like honeycombs, and more recently developed lattice structures [2], [3], [4], used as cores in sandwich assemblies, proved to have better mechanical properties than other types of cores. Still, the drawbacks of these periodic cellular structures are represented by a higher production cost especially caused by the core production technology, the amount of base material consumed - especially in the case of honeycombs, and the joining technology of sandwich components.

An expanded periodic cellular core, Figure 1, is proposed at *Transilvania* University of Braşov, produced through the expansion of a continuous sheet material that has previously undergone intercalated cuts and perforations in such a way that a pattern of opened cells has been formed. Due to this simple fabrication principle and the reduction of the consumed base material implied, this type of core may represent a cheaper and more convenient alternative to the above-mentioned cellular structures.

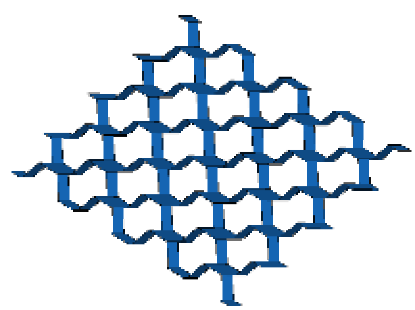

Fig. 1. *Expanded cellular core*

According to Gibson & Ashby [1] the most important core material data for the design and calculation of sandwich structures are out-of-plane moduli and strengths. Therefore, the purpose of the present study

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is twofold: firstly, it is intended to investigate the failure modes in the case of the out-of-plane compressive loading as a function of geometric parameters of the core, and secondly, it aims to evaluate the out-of-plane compressive modulus and strength.

2. Geometry of the Expanded Cellular Core

The relations that define the cellular topology have been derived [5], by identifying a unit cell, Figure 2, where: *A* - angle which defines the shape of the cell [deg]; *G* - expansion degree [deg]:

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

h - height of the unit cell [mm]:

$$h = 2(c - b)\sin G; \quad (2)$$

t - length of the unit cell [mm]:

$$t = \frac{2c}{\cos G}; \quad (3)$$

w - width of the unit cell [mm]:

$$w = 2l(1 + \sin B), \quad (4)$$

l - length of the cell flank [mm]; *c* - distance between two transversal cuts [mm]; *2b* - width of the perforated area [mm]; it was considered having a constant value of 2 mm; *g* - thickness of the sheet material [mm]; it was considered having a constant value of 0.15mm; *d* - distance between two opposite cell walls in longitudinal direction [mm].

The *B* angle has been denoted and used to simplify the relations.

An important characteristic of a cellular structure is relative density. In the case of the expanded structure discussed, relative density will depend on the geometric parameters according to Equation 5 [5]:

$$\rho_r = \frac{\rho}{\rho_s} = \frac{4g}{2(1 + \cos A)\, l \sin A}. \quad (5)$$

Figure 3 shows how relative density varies in terms of the cell shape *A* parameter, also considering different values for *l/c* ratio [5].

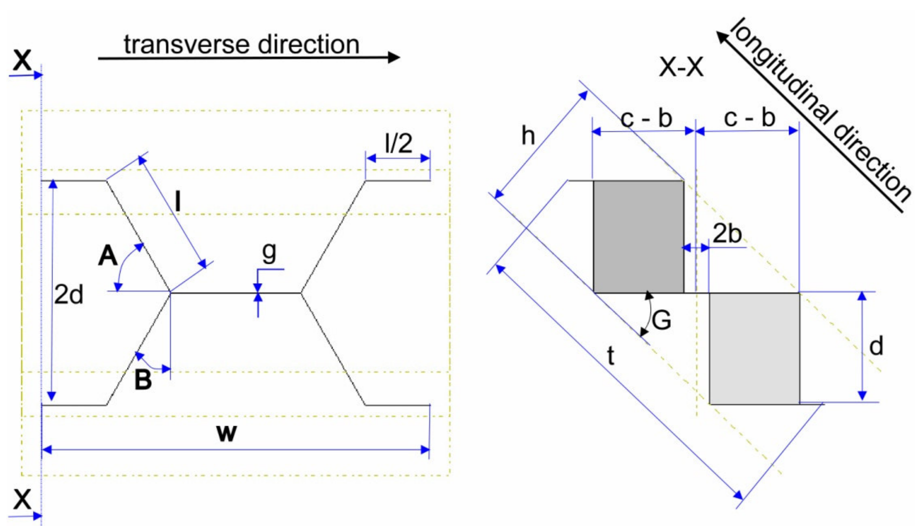

Fig. 2. *Geometric parameters of a unit cell*

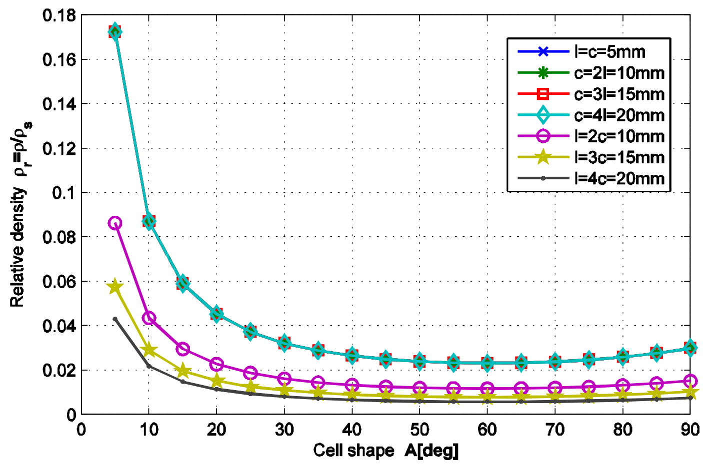

Fig. 3. *The relative density in terms of the cell shape "A" parameter*

3. Compressive Behaviour of the Expanded Core

In order to investigate the core compressive behaviour function of the core topology, nonlinear finite element simulations were performed using ABAQUS/Standard software. Representative unit cells were modelled by keeping the angle *A* constant at 60 degrees (in which case lower values of relative density are obtained, see Figure 3), and varying the ratio of *l* to *c*, see Figure 2. Thus, five different cases were considered, with different corresponding expanding degrees, as it is shown in Table 1.

Analysed cases Table 1

	l/c ratio	Expanding degree *G* [deg]
Case 1	$c = 2\,l$	23.41
Case 2	$l = c$	40.89
Case 3	$l = 2\,c$	60
Case 4	$l = 3\,c$	68.95
Case 5	$l = 4\,c$	73.9

To create the mesh, general purpose elements (S4R) were used. The S4R element is a four-node element; each node has three displacement and rotation degrees of freedom, respectively. As boundary conditions, all the degrees of freedom of the nodes from the lower face were restricted (pinned), while on the upper face nodes, a displacement of 1 mm in the negative Y-axis direction was applied, Figure 4.

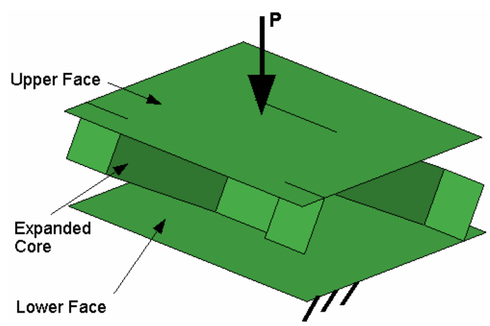

Fig. 4. *Unit cell FE model*

Symmetry conditions were also taken into consideration, on all four lateral sides of the unit cell.

The material properties used in the ABAQUS simulation, Table 2 and Table 3, represent the response of an annealed type 304 stainless steel sheet material that was subjected to the same thermal cycle encountered during the fabrication of the brazed sandwich structures [2].

Table 2
Elastic material properties

Young's Modulus, [MPa]	Poisson's Ratio
201	0.29

Table 3
Plastic material properties

Yield Stress, [MPa]	Plastic Strain, [%]
176	0
318	0.05
425	0.1
525	0.15
610	0.2
685	0.25
760	0.3
818	0.35
880	0.4

The reaction forces at the lower face nodes were measured and plotted against the displacement of the upper face nodes, Figure 5.

It may be observed that the deformations and failure modes of the core are different from each of the five cases, as follows:

Case 1: in this case, the response of the structure to a normal compressive loading consists in an initial elastic behaviour followed by the bending of the central wall of the cell (the wall that defines the *G* angle), starting from the contact areas with the upper and lower faces, Figure 6. This plastic deformation can also be observed on the corresponding load-displacement curve, Figure 5. After the maximum load is reached, the measured load starts to decrease slowly, corresponding to the plastic deformation of the lateral cell walls.

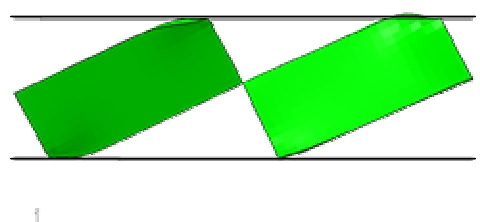

Fig. 5. *c = 2 l =10 mm, G = 23.41 deg*

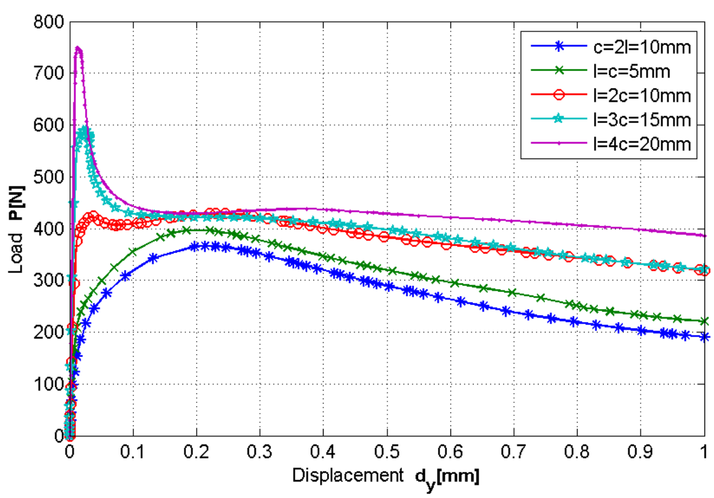

Fig. 6. *Compression FE simulation results*

Case 2: the behaviour of the structure in this configuration, Figure 7, is much the same as the one in the previous case, only that the plastic deformation occurs on a large area of the central wall of the cell. The maximum load reached is slightly higher than that in case 1, Figure 5.

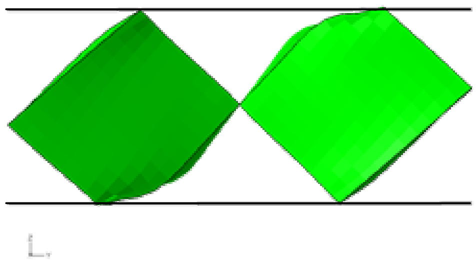

Fig. 7. *l = c = 5 mm, G = 40.89 deg*

Case 3: the response of the structure, Figure 8, consists in an initial elastic behaviour followed by a small plastic deformation. In addition to this, plastic buckling of the central wall of the cell occurs. After the buckling load is reached, there is a small decrease in load carrying capacity, followed again by a small increase caused by the homogenous plastic deformation, Figure 5.

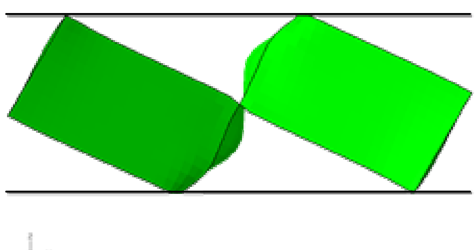

Fig. 8. *l = 2c = 10 mm, G = 60 deg*

Case 4: in this case, Figure 5 shows that after the initial elastic behaviour and a small amount of plastic deformation (close to the contact areas of the core with the upper and lower faces, Figure 9), a collapse of the core is caused by plastic buckling of the central wall of the cell. The maximum load reached is close to 600 N. Beyond the buckling load a plateau can be observed, caused by the continuous plastic deformation of the lateral cell walls, which seems to start from the neutral axis of the sandwich structure to the lateral faces, Figure 9.

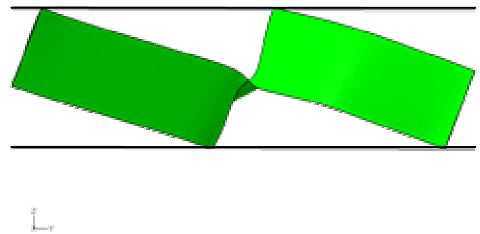

Fig. 9. *l = 3 c = 15 mm, G = 68.95 deg*

Case 5: the collapse of the core is caused by the plastic buckling of the central wall of the cell, Figure 10. The buckling load is almost 750 N, Figure 5. The homogenous plastic deformation occurs after the buckling load is reached and it can be observed in Figure 5 as a plateau.

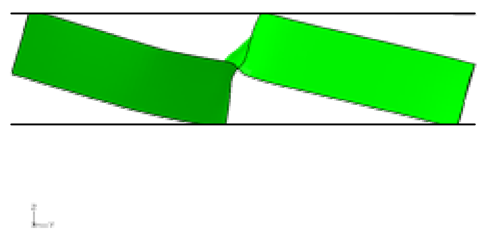

Fig. 10. *l = 4 c = 20 mm, G = 73.9 deg*

4. Compressive Modulus of the Expanded Cellular Core

Once load-displacement curves have been determined, Figure 5, the compressive modulus of the expanded cellular core can be obtained, by using Equation 6 [6]:

$$E_c = \frac{P \cdot h}{w \cdot t \cdot d_y}. \tag{6}$$

By considering Equations 2, 3 and 4, Equation 6 becomes:

$$E_c = \frac{\left(\dfrac{P}{d_y}\right)(c-b)\sin G\cos G}{c\,l\,(1+\sin B)}. \tag{7}$$

Based on Equation 7 and considering the

five cases treated above, Figure 11 shows how the compressive modulus of the expanded core modifies in terms of the expansion degree. As it has been expected, the compressive modulus increases with the expansion degree.

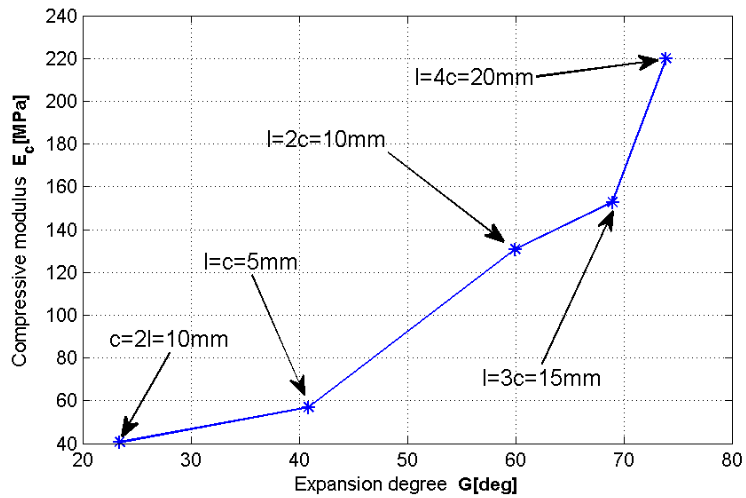

Fig. 11. *Normal compressive modulus vs. expansion degree*

Figure 12 illustrates the way in which the normal compressive modulus varies in terms of the relative density of the core (determined by Equation 5). The compressive modulus of the core will increase with the increasing of *l/c* ratio.

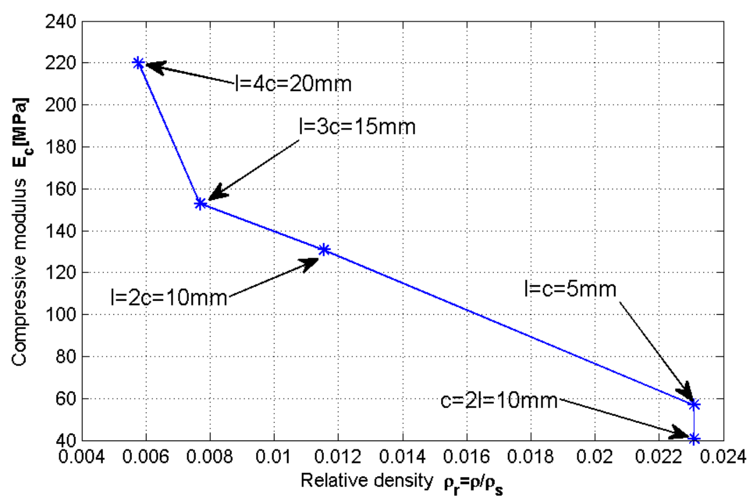

Fig. 12. *Normal compressive modulus vs. relative density of the expanded core*

5. Compressive Strength of the Expanded Cellular Core

The strength of the expanded cellular core can also be evaluated using Equation 8 [6]:

$$\sigma_c = \frac{P}{w \cdot t}. \tag{8}$$

According to Equations 3 and 4, the strength becomes:

$$\sigma_c = \frac{P \cos G}{4 l c (1 + \sin B)}, \tag{9}$$

where *P* represents the failure load, resulted from Figure 5.

Compressive strength can thus be evaluated for the five cases considered above. Figure 13 illustrates the manner in which relative density - and thus the topology of the expanded core - influences compressive strength.

As it has been expected, Figure 3 shows that compressive strength increases with relative density. Still, it can be seen that compressive strength starts to decrease when *l/c* ratio becomes smaller than 1. In these cases, relative density will not change, see Figure 3. The highest value of compressive strength is obtained when ratio *l/c* = 1, which corresponds to a value of 40.89 deg for the expansion degree *G*.

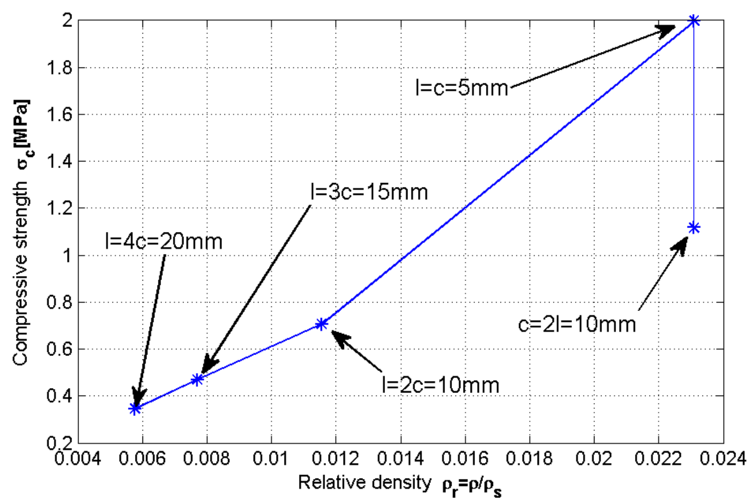

Fig. 13. *Compressive strength in terms of relative density of the expanded core*

4. Conclusions

Numerical simulations using ABAQUS/ Standard software have been performed in order to investigate the compressive behaviour of an expanded periodic cellular core in terms of core topology, using the material data of an annealed stainless steel type 304. The results have shown that when *l/c* < 1, the collapse of the expanded cellular core is caused predominantly by plastic buckling of the central wall of the cell. In the case of *l/c* > 1, the homogenous plastic deformation is predominant.

The normal compressive modulus and the normal compressive strength of the expanded cellular core have also been assessed in terms of the geometrical parameters of the core. In order to obtain the highest compressive strength of the expanded periodical cellular structure, it is compulsory that $l/c = 1$, which corresponds to a value of 40.89 deg for the expansion degree G (in case of A = 60 deg).

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