# Performance of Sandwich Components with Chiral Topology Cores

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**Abstract** Two thin plates with a stabilizing medium placed between them can be an ideal component for large and lightweight structures with increased strength, stiffness and stability. The application of the novel chiral cellular geometry will lead to the development of structural components with superior elastic and impact resilient properties. This paper proposes the design of lightweight square sandwich panels with aluminum sheets and a core made with a chiral geometry network having parallelogram-shaped nodes. Finite element analyses were undertaken in order to characterize the behavior of the considered panels as having supported edges, and loaded under lateral pressure. Also, the loading in torsion was analyzed in the case when two opposite corners are supported and in the other two corners equal and opposite normal forces are applied. For this loading experimental measurements were also done by using strain gages. The new meta-tetrachiral configurations under investigation can provide significant improvements in the mechanical performance of sandwich components, and may also be considered for advanced designs.

**Keywords** Sandwich panel, Auxetic core, Meta-chiral topology, Finite element analysis, Strain gage

## 1. Introduction

The strength and the stiffness properties of a sandwich panel are dependent to a great extent both on the behavior of the faces and of the structure used as core. Classical honeycomb core adopts a saddle shape (anticlastic curvature) upon out-of-plane bending, because its Poisson's ratio is positive. In order to manufacture curved panels, cellular cores that exhibit auxetic properties (negative Poisson's ratio) are used, because of their tendency to form dome-shaped surfaces. Consequently, curved sandwich panels with auxetic cores are basic components of advanced structures, first of all in the aircraft and automotive fabrication. It is evident that the analysis of the behavior of cores and sandwich panels under mechanical and thermal loading is of importance for designers.

In paper [1], the finite element method has been applied to characterize the mechanical properties of re-entrant (auxetic) honeycombs which may be used as cores for sandwich panels with any special properties. In the last two decades, a number of cellular structures have been extensively analyzed [2]-[9]. Especially the periodic core structures with chiral topologies, which contain a number of interconnected basic blocks, have attracted considerable attention. A basic block is "chiral" if it is not super imposable on its mirror image. A basic block is consisting of a node with a number of 3, 4 or 6 ligaments attached to it (Fig. 1). Also, left handed or right handed blocks may be constructed.

In the case of a chiral structure, the nodes are attached on the opposite sides of the same ligament (Fig. 2, a). It is possible to attach the nodes on the same side of each ligament and the corresponding structure will be denominated anti-chiral (Fig. 2, b). A hybrid construction, containing some nodes which are attached to the same side of the ligaments and some others to opposite sides of the ligaments, will be referred as meta-chiral (Fig. 2, c). In two-dimensions (2-D), the nodes may be circular, hexagonal, square, rectangular or with other geometry.

There are many papers which deal with the geometries and the properties of auxetic materials, but there is little information on the behavior of the sandwich panels with chiral configured cores. In this paper, the meta-chiral structure with parallelogram-shaped nodes as in Fig. 3 will be analyzed separately, and as a core of a sandwich panel.

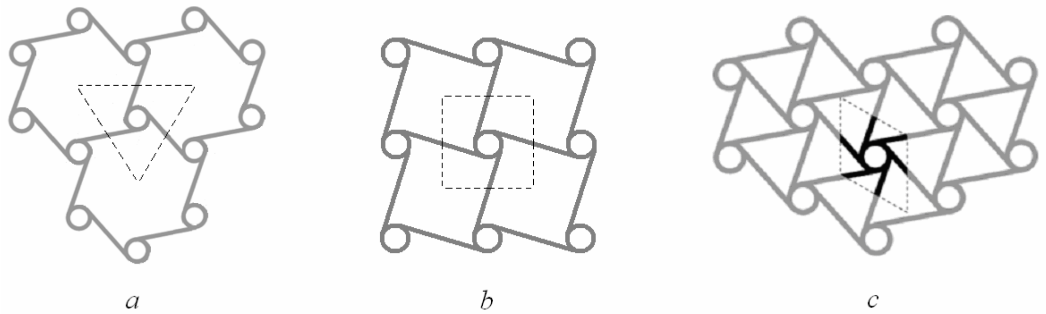


Figure 1. Basic blocks for three chiral structures: a) trichirals, b) tetrachirals, c) hexachirals

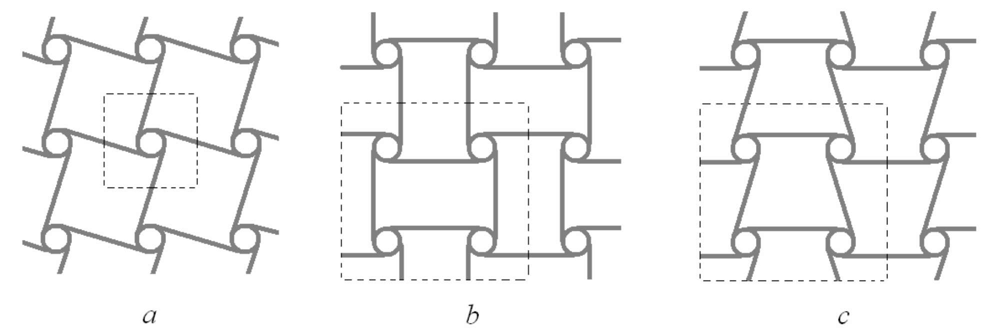


Figure 2. Structures from components of order 4:
a) tetrachirals, b) anti-tetrachirals, c) meta-tetrachirals

It is to note that in the analytical evaluations of auxetic in-plane properties of 2-D chiral, anti-chiral and meta-chiral structures, two different approaches were used: a) rigid ligaments and nodes, connected together through ideal hinges [2]; b) flexible ligaments connected with rigid or deformable nodes [9]. Also, it is possible to evaluate the out-of-plane mechanical properties of a chiral lattice analytically or by means of finite element analysis (FEA) [8,9].

## 2. Geometry of the analyzed structure and the finite element model

The behavior of the panel presented in Fig. 3 was evaluated by using a FEA model, with ANSYS [10]. The sandwich panel has sheets made from an aluminum alloy (1050 H24) of thickness $t_f$ = 1 mm, glued with araldite AW 106/HV953 U to the core made from rigid polyurethane strips having a section of 5 x 25.4 mm inside the panel and 10 x 25.4 mm on the border of the panel.

The FEA makes possible the characterization of the sandwich panels under several aspects: rigidity, state of stress, fundamental eigenfrequencies and modes of vibration, stability. There were analyzed several cases of loading:

1) simply supported plate, loaded by a lateral pressure of 0.07 MPa;
2) cylindrical bending with the panel supported on two opposite edges and loaded by a lateral pressure of 0.05 MPa;
3) cylindrical bending with the panel supported on the other two opposite edges and loaded by the same lateral pressure of 0.05 MPa;

4) torsion of the panel by applying two equal forces in opposite corners and restricting the movement of the other two corners [11].

In the numerical model the adhesive was considered only in between the upper and lower aluminum sheets and the chiral core which presumably behaves as a monobloc structural component, although the core was built as a “puzzle” from separate parts glued between them.

For the used materials the following material parameters were adopted: aluminum – $E$ = 69000 MPa, $\nu$ = 0.33, $\sigma_u$ = 138 MPa (ultimate strength), $\sigma_{y\,0.2}$ = 132 MPa (0.2% offset yield limit), density 2700 kg/m$^3$; araldite AW 106 – $E_a$ = 1350 MPa, $\nu_a$ = 0.45, $\sigma_{ua}$ = 33 MPa, $\tau_{ua}$ = 23 MPa, density 1500 kg/m$^3$; rigid polyurethane foam – $E_f$ = 220 MPa, $\nu_f$ = 0.3 , density 301 kg/m$^3$. The allowable stresses will be considered as 100 MPa in aluminum, 5 MPa in the polyurethane foam and 20 MPa in the adhesive.

The dimensions of the panel are: $a$ = 400 mm, $b$ = 48 mm, $c$ = 32 mm, $t_f$ = 1 mm (thickness of the sheets), $t_a$ = 0.3 mm (thickness of the adhesive), $t_c$ = 25.4 mm (thickness of the core), $t_s$ = 5 mm (thickness of the strips used to built the core), $t_b$ = 10 mm (thickness of the border).

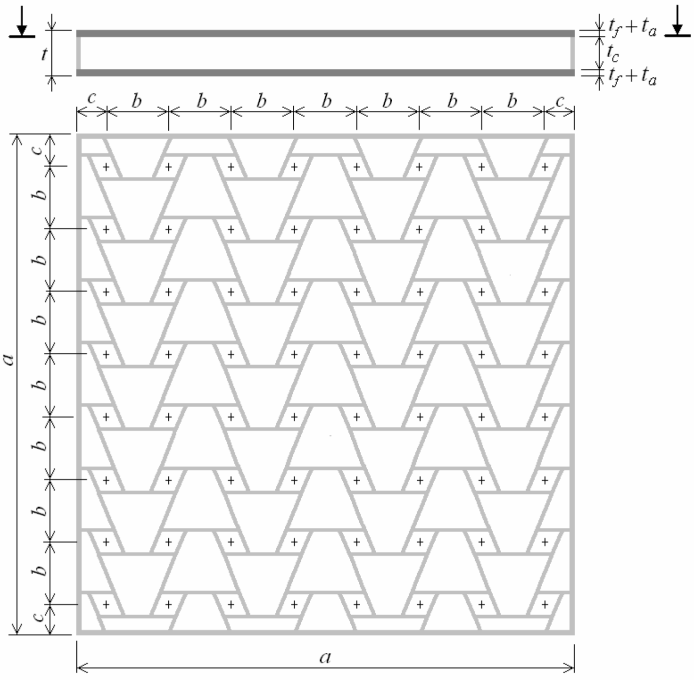

Figure 3. Geometry of the analyzed panel

In generating the chiral network (Fig. 4) was used the basic block obtained by adding to the configuration from Fig. 5 its own image in mirror. The FE mesh is done by using solid 8-noded elements (Brick 8), and resulted as having 134728 elements and 185706 nodes. Two layers of elements were used over the thickness of the strips which form the chiral core and through the thickness of the sheets, and one layer of elements through the thickness of the adhesive.

After a preliminary study it was established that a geometrically nonlinear analysis (large displacements) doesn’t lead to results clearly different from the ones obtained in a small displacement analysis, therefore all the following calculations were done only in the second hypothesis.

By using the densities of the materials mentioned previously the total mass of the sandwich panel resulted as 1.335 kg, from which the mass of the sheets is 65% (0.864 kg), of the core is 31% (0.418 kg), and of the adhesive as 4% (0.053 kg). It is to observe that the mass of proposed chiral foam core represents 35% of the mass corresponding to a compact core made from the same foam and having the same overall sizes, which is of 1.2 kg.

Data were considered in the SI system, therefore in the figures displacements were obtained in meters, and stresses in $N/m^2$ ($10^6$ $N/m^2$ = 1 $N/mm^2$ = 1 MPa).

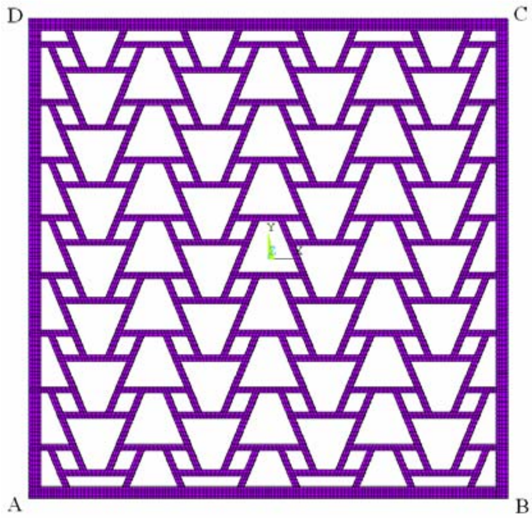


Figure 4. The core discretized with 8-node brick-type finite elements

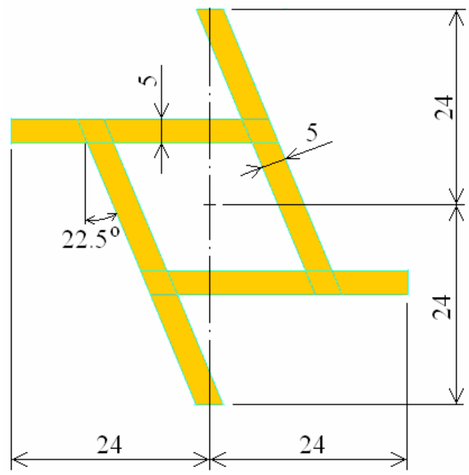


Figure 5. Geometry of the basic semi-block of the meta-tetrachiral core

## 3. Evaluation of in-plane auxetic properties of the core

The chiral core was initially analyzed separately in order to establish the coefficients of transversal contraction (or of transversal swelling), notated as $\nu_{xy}$ and $\nu_{yx}$. The displacements in the plane XY (median plane of the core) were established in two situations (Fig. 4):

I displacements blocked in the direction X on the edge AD and an imposed displacement on the opposite edge (UX = 1 mm);

II displacements blocked in the direction Y on the edge AB and an imposed displacement on the opposite edge (UY = 1 mm).

In general, if $L_x$ and $L_y$ are the overall dimensions of the panel (length and width), the two values of the “Poisson’s coefficients”, associated to the situations defined in I and II are to be calculated with the relations:

$$\nu_{xy} = -(\Delta L_{y,I} / L_y)/(\Delta L_{x,I} / L_x), \qquad \nu_{yx} = -(\Delta L_{x,II} / L_x)/(\Delta L_{y,II} / L_y). \tag{1}$$

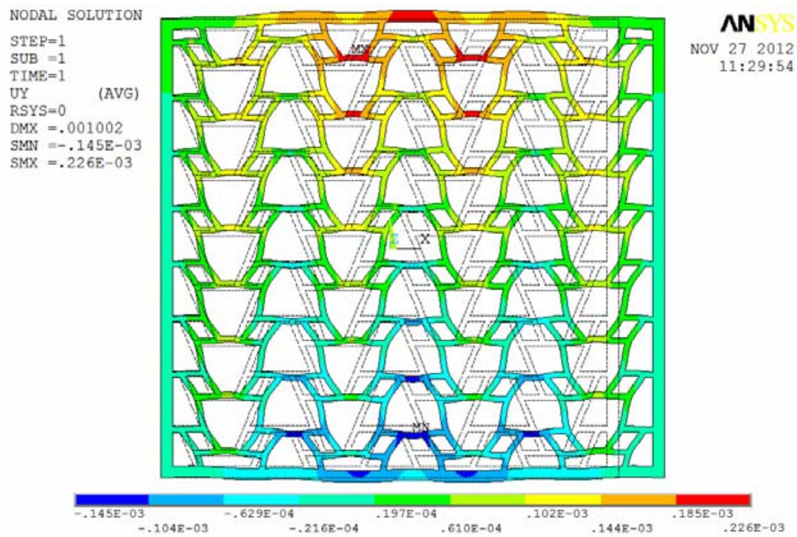


Figure 6. Deformed shape of the core when a relative displacement of 1 mm between the vertical sides is imposed

The results presented in Figs. 6 and 7 show that $\Delta L_{y,I} = 0.226 - (-0.145) = 0.371$ mm, and $\Delta L_{x,II} = 0.159 - (-0.159) = 0.318$ mm. Taking into account that $\Delta L_{x,I} = \Delta L_{y,II} = 1$ mm and that $L_x = L_y = a$, from (1) resulted $\nu_{xy} = -0.371$ and $\nu_{yx} = -0.318$. These negative values show that the core which will be used to build the sandwich panel has auxetic properties.

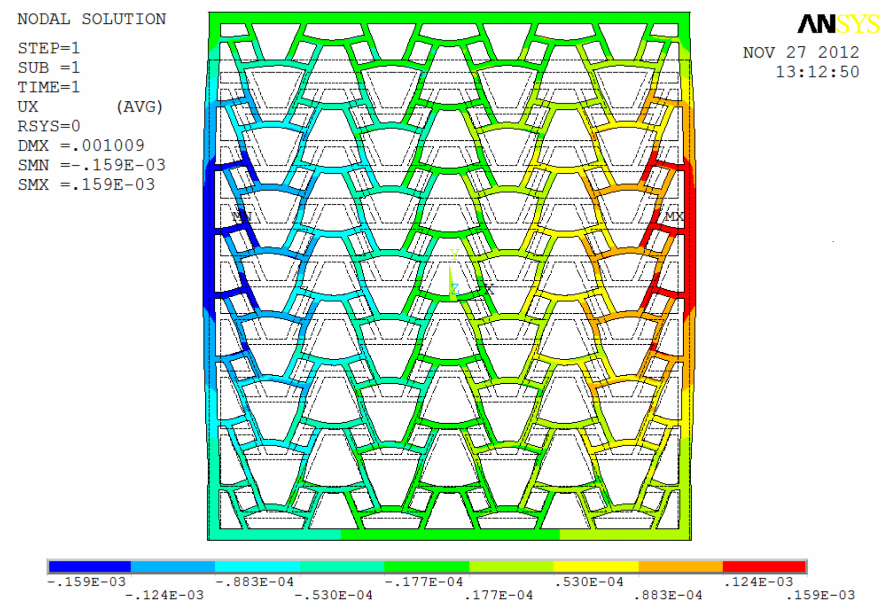


Figure 7. Deformed shape of the core when a relative displacement of 1 mm between the horizontal sides is imposed

## 4. Results of the FEA in the case of the panel under lateral pressure

### 4.1. Case of panel simply supported on the contour

The applied loading is a lateral pressure of 0.07 MPa. The obtained results are given in Table 1 and in Figs. 8-13.

It is to be noticed that the maximum von Mises equivalent stresses are lower than the allowable stress values in all the materials. The sandwich plate has a high stiffness as indicated by the maximum deflection (2.589 mm) and a high fundamental eigenfrequency (365 Hz). There is no risk to lose the stability of the plate as the coefficient of safety is 5.97 for the first local buckling mode. Fig. 13 shows a non-uniform distribution of the reactions along the supported contour, thus being explained the increased values of the stresses towards the middle sides of the sheet (Fig. 9).

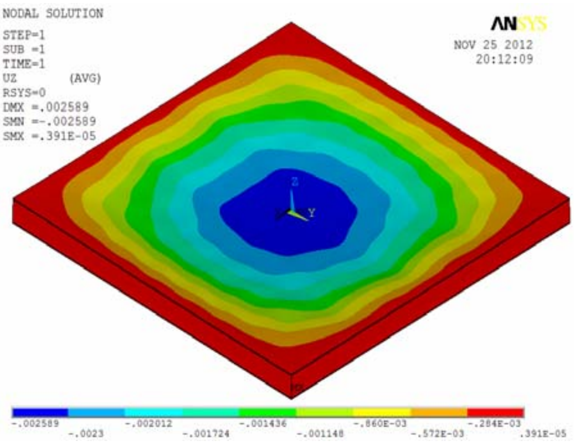

Figure 8. Deformed shape of the panel

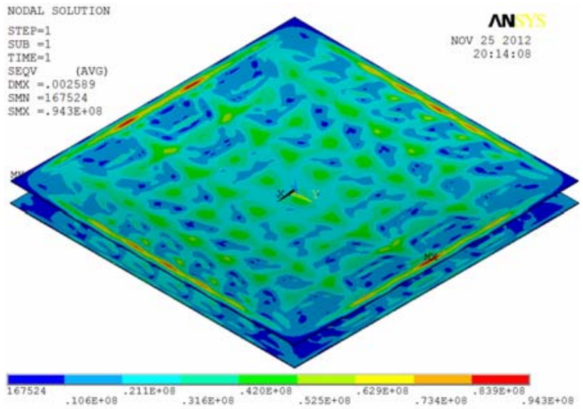

Figure 9. Equivalent stresses in the aluminum sheets

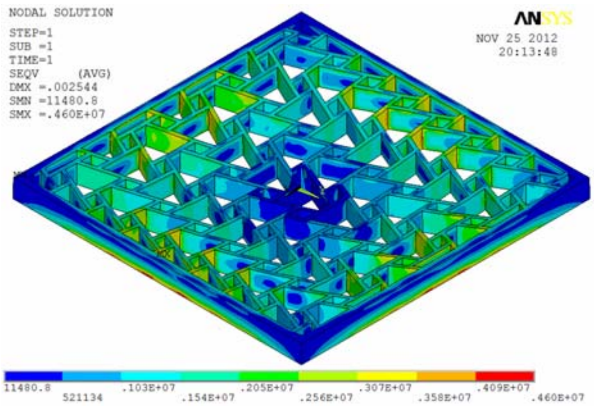

Figure 10. Equivalent stresses into the core

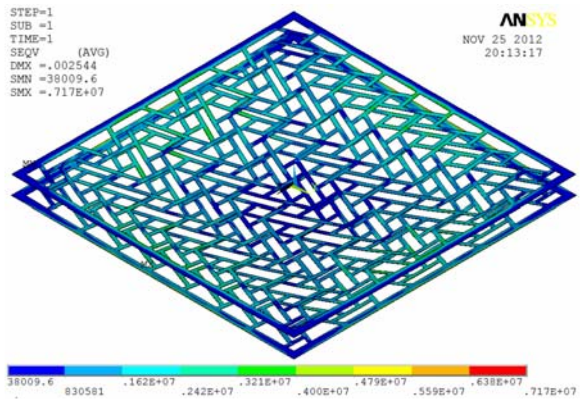

Figure 11. Equivalent stresses into the adhesive

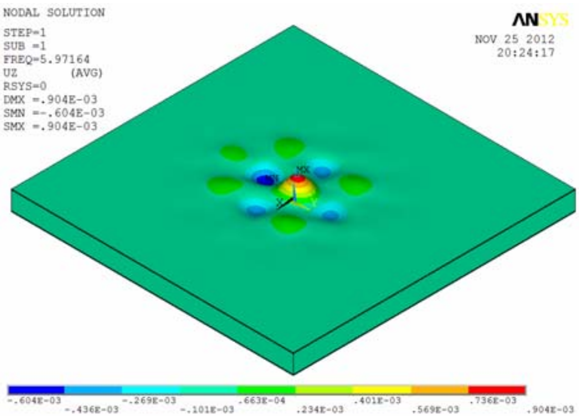

Figure 12. First mode of local buckling

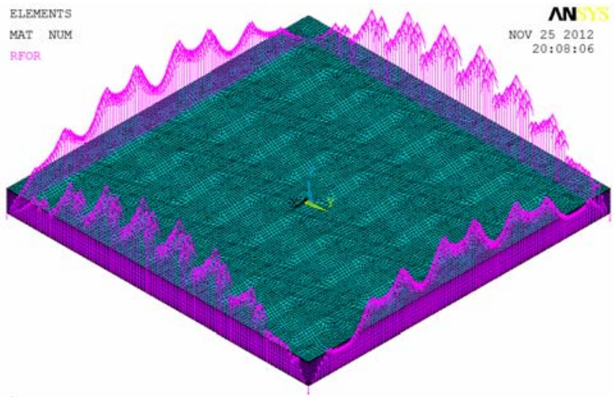

Figure 13. Distribution of the support reactions on the contour of the panel

## 4.2. Case of panel simply supported on the sides AB and CD (Fig. 4)

The lateral pressure is 0.05 MPa. The obtained results are presented in Table 1 and in Figs. 14-17.

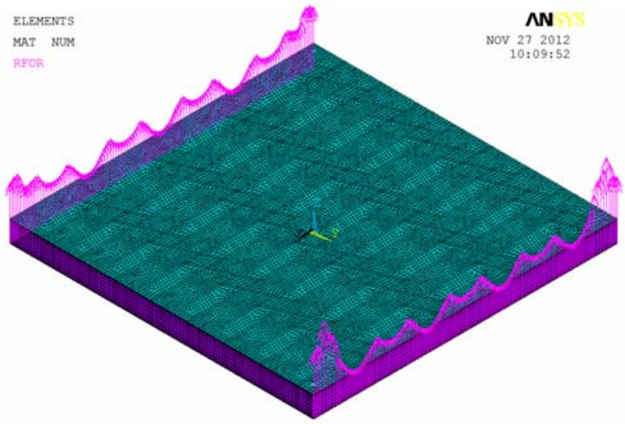


Figure 14. Distribution of the support reactions

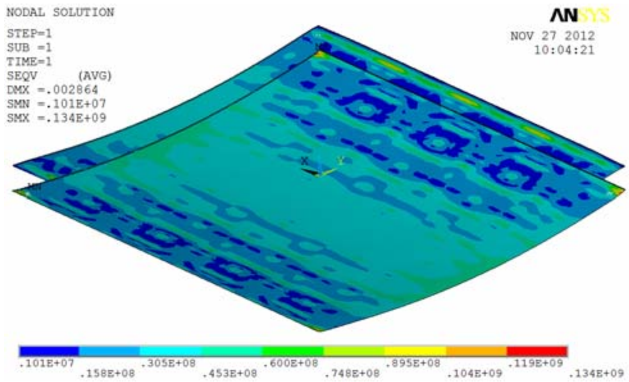


Figure 15. Equivalent stresses in the aluminum sheets

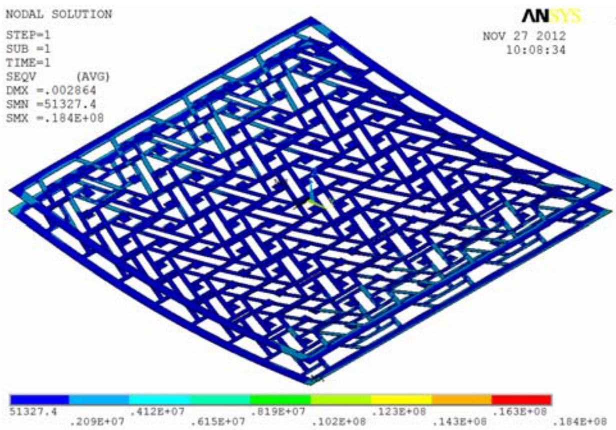


Figure 16. Equivalent stresses in adhesive

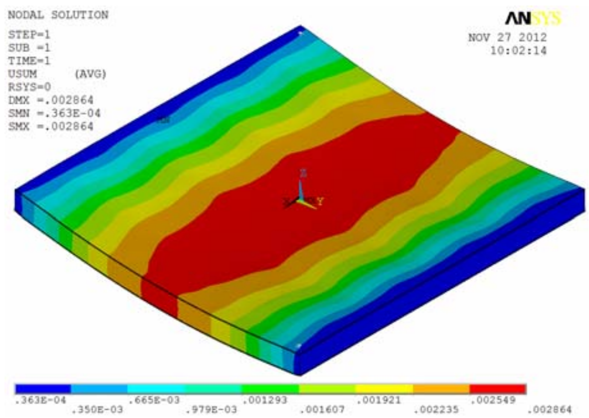


Figure 17. Deformed shape of the panel

## 4.3. Case of panel simply supported on the sides AD and BC (Fig. 4)

The loading is done by a lateral pressure of 0.05 MPa. The obtained results are presented also in Table 1 and in Figs. 18 and 19.

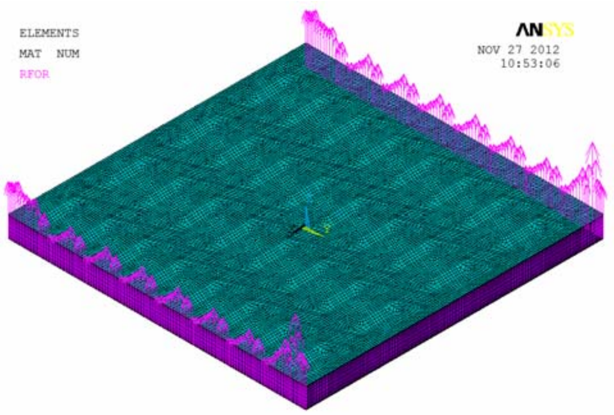


Figure 18. Distribution of the support reactions

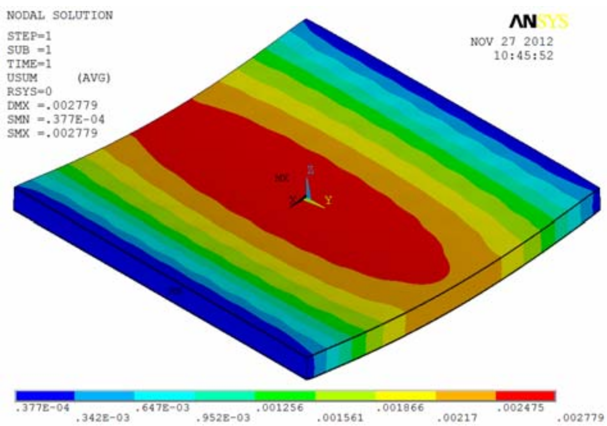


Figure 19. Deformed shape of the panel

Table 1. Results of the finite element analyses

| Load case | Type of analysis | Maximum von Mises equivalent stresses [MPa] | | | Maximum deflection [mm] | Buckling safety coefficient | Fundamental eigenfrequency [Hz] |
|---|---|---|---|---|---|---|---|
| | | Sheets | Core | Adhesive | | | |
| 1 | linear | 94.3 | 4.6 | 7.17 | 2.589 | 5.97 | 365 |
| 1 | nonlinear | 96.6 | 4.58 | 7.12 | 2.581 | 5.97 | 365 |
| 2 | linear | 134 | 8.95 | 18.4 | 2.864 | 8.09 | 262 |
| 3 | linear | 133 | 8.93 | 18.3 | 2.779 | 8.24 | 265 |

In the two cases of cylindrical bending the stresses in the sheets, but especially in the core are unacceptably high. As the stresses in the foam have to be reduced to half, the loading has to be decreased from 0.05 MPa to 0.025 MPa. If the pressure has an imposed value (as 0.05 MPa) the thickness of the sheets may be increased and/or a foam with higher density and resistance has to be chosen.

It is interesting to notice that the distribution of the reactions along the edges on which the panel is supported is quite uniform (Figs. 14 and 18), but there are peak values in the vicinity of the corners where extreme values of the stresses in all the components were obtained.

Although it was expected to obtain differences between the two cases of cylindrical bending, the results are very similar; this represents an advantage given by the use of the meta-tetrachiral configuration.

## 5. Results of the FEA in the case of the panel under torsion

The loading scheme is presented in Fig. 20, in each corner of the plate being applied a force of 500 N, which in the numerical model were distributed on squares of 20x20 mm, as to avoid undesired local effects. The obtained results are presented in Figs. 20-23. In the aluminum sheets the maximum equivalent stress obtained in the corners is 65 MPa (Fig. 22), and in the center is 25 MPa (Fig. 23). In Fig. 23 the middle of the panel is considered the origin of the horizontal axis. The equivalent stress in the adhesive was obtained as about 2 MPa along the border of the core, and a maximum value of 6 MPa resulted again in the corners. In the chiral core the equivalent stress was almost zero in the middle area, about 1 MPa in the border, and a maximum value of 2.9 MPa was again obtained in the corners.

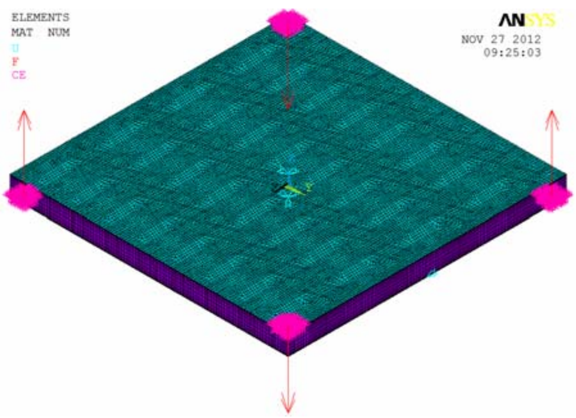


Figure 20. The loading scheme

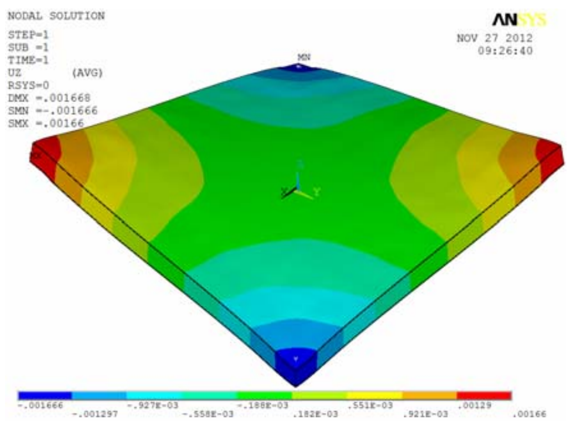


Figure 21. Displacement of the twisted panel

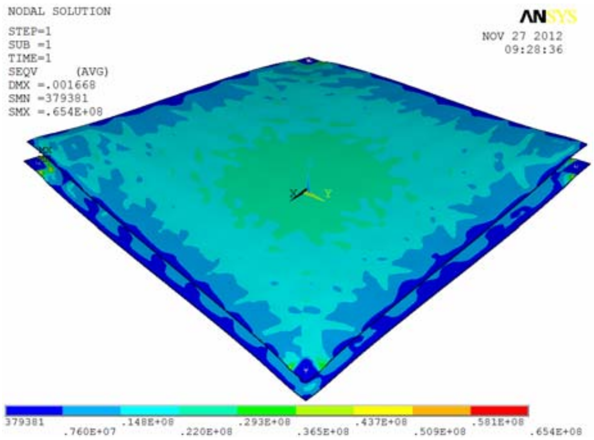


Figure 22. Equivalent stresses in the sheets

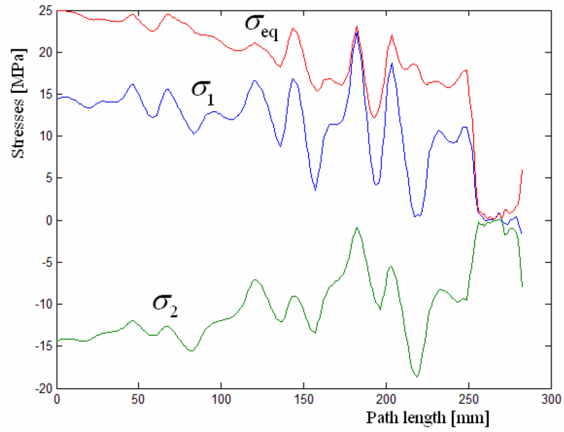


Figure 23. Variation of stresses $\sigma_{eq}$, $\sigma_1$, $\sigma_2$, along a half of the diagonal, on the surface of the panel

## 6. Experimental evaluation of the sandwich panel under torsion

In Fig. 24 (left) is shown the core of the sandwich panel tested in torsion with the loading scheme from Fig. 24 (right). A strain gage with two measuring grids (SG 1 and SG 2) of type XY93 10/120 (HBM, Germany) was positioned in the middle of the panel along its diagonals in order to measure the principal strains. With these strains were calculated the principal stresses $\sigma_1$, $\sigma_2$, and then the von Mises equivalent stress, $\sigma_{eq}$. For an applied force of 500 N (as in the FEA model) the experimentally established equivalent stress resulted as 23.55 MPa, being a little bit smaller than the 25 MPa value obtained numerically. This result validates the modeling procedure established in the FEA.

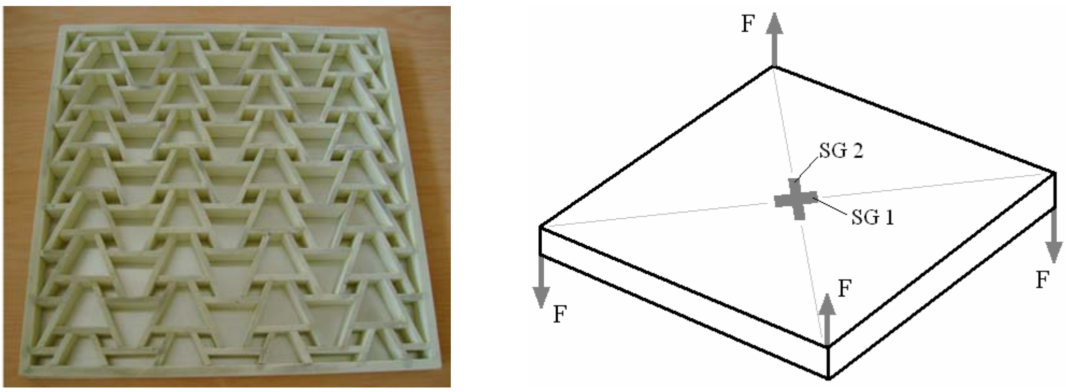


Figure 24. The meta-tetrachiral core manufactured from rigid foam strips and the loading scheme

## 7. Conclusions

The meta-tetrachiral core analyzed hereby is a new solution which has auxetic properties, and the resulting sandwich panel is stiff and light. Although it has only one plane of symmetry its behavior in bending (Table 1) is almost the same on the two in-plane directions.

This type of geometry, characterized by robust cells having thick walls, confers an important advantage concerning the local stability of the core.

We intend to use this meta-tetrachiral core for curved sandwich panels. By changing the geometry of the basic block (Fig. 5) one can obtain similar chiral core geometries with properties which worth to be investigated. Due to the simple manufacturing technology such panels can be obtained with significant economical advantages.

**Acknowledgements**

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