

## IMPULSIVE PRESSURE RESPONSE OF SANDWICH PLATES WITH AUXETIC CORE

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### ABSTRACT

The dynamic behaviour of sandwich plates with auxetic core subjected to air blast loading is investigated numerically. The plates are considered to be made of carbon/epoxy face sheets and auxetic cores in the shape of “antitetrachiral” and “missing rib”. The air blast loading is described by Friedlander decay function. The sandwich plate subjected to air blast loading is modeled by using the finite element method. An explicit analysis is performed. The displacement time history and the displacement and stress distributions on the plate and auxetic core are obtained at the time of peak displacement. The results obtained for sandwich plates with antitetrachiral and missing rib auxetic cores are compared and discussed.

**Keywords:** auxetic materials, sandwich plate, blast loading, finite element method.

### INTRODUCTION

The negative Poisson's ratio could be an important factor on the blast resistance of structures. The materials with negative Poisson's ratio which are named as “auxetic” were first discovered by Evans (Evans, 2000). Since auxetics have high shear modulus and shock absorption capability, they show high resistance against in-plane crashes and could be used in cars' crash boxes, airplanes, life vests, etc. For their interesting material properties, researchers investigated auxetic materials. To name a few, Subramani et. al. performed tensile tests on the materials with Poisson's ratios between -0.3 and -5.2 (Subramani, 2014). They stated that the material with the lowest Poisson's ratio (-5.2) showed the highest tensile strength. It can be said that the tensile strength is increased as the Poisson's ratio is increased in the negative direction. Alderson and Alderson compared impact analysis for both auxetic and non-auxetic materials (Alderson, 2007). They observed that much more damage occurred in non-auxetic materials for the specimens they used. Also, for non-auxetic materials, the length of the part affected by the damage is bigger than the auxetic ones. Evans focused on the negative Poisson's ratio at the molecular level (Evans, 2000). He summarized producing a larger model from molecular level mechanism. Ma et al. studied to improve the antitetrachiral structure with adding polymer to cylinders (Ma et. al., 2013). All of the cylinders of antitetrachiral shape are filled with polymer to investigate the strength improvement. Both numerical analysis and experimental tests are performed. It is found that filling the cylinders does not change overall strength slightly.

The materials with negative Poisson's ratio are very rare in nature. But, the negative Poisson's ratio could be obtained by considering special geometrical shapes for the plate structures. In this study, the materials with negative Poisson's ratio are created by using two different

geometrical shapes. The sandwich plates used these auxetic shapes as a core material are investigated under air blast loading numerically and results are discussed in detail.

## NUMERICAL STUDY

The auxetic cores with negative Poisson's ratio are created by using two different geometrical shapes, namely, "antitetrachiral" (Fig.1) and "missing rib" (Fig.2). The sandwich plates with auxetic cores are modeled by using the finite element method. The face sheets are made of CFRP (Carbon Fiber Reinforced Polymer) laminated plates. The stacking sequence of laminated sandwich plate is considered as  $[0/90/0/90/\text{core}/90/0/90/0]$ . Each layer of the face sheets is modeled by using 2916 shell elements. The layers are connected to each other by using tie-break contact. Both top and bottom face sheets consist of four layers of carbon/epoxy. The thickness of each layer is taken as 0.2 mm. The auxetic core is made of ABSplus material. The core is also modeled by using shell elements. The total number of elements used for the auxetic cores in antitetrachiral shape and in missing rib shape are 4068 and 3764, respectively. The dimensions of the plate is 135 mm x 135 mm. The diameters of the cells in antitetrachiral core is 10 mm and the central distance is 25 mm. The core wall thickness is taken as 1 mm and 0.5 mm. The core thickness is taken as 5 mm for all sandwich plates. The material properties used for face sheets and auxetic core are shown in Table 1. The sandwich plates considered in this study are shown in Table 2. The finite element model of SP\_1 plate is shown in Fig. 3.

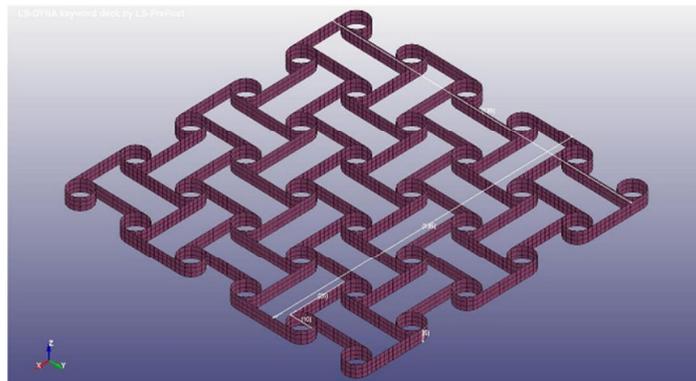


Fig. 1 - Auxetic core in antitetrachiral shape

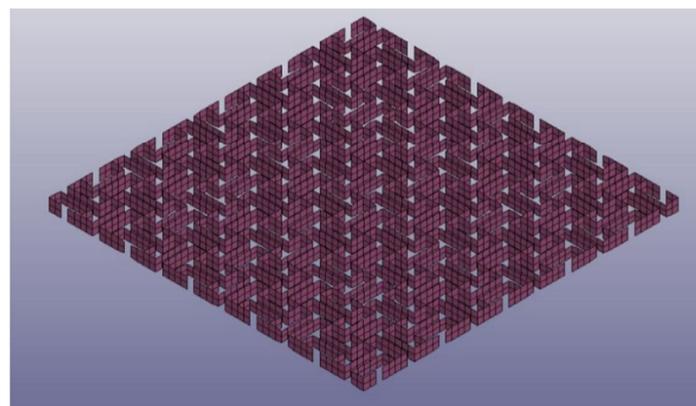


Fig. 2 - Auxetic core in missing rib shape

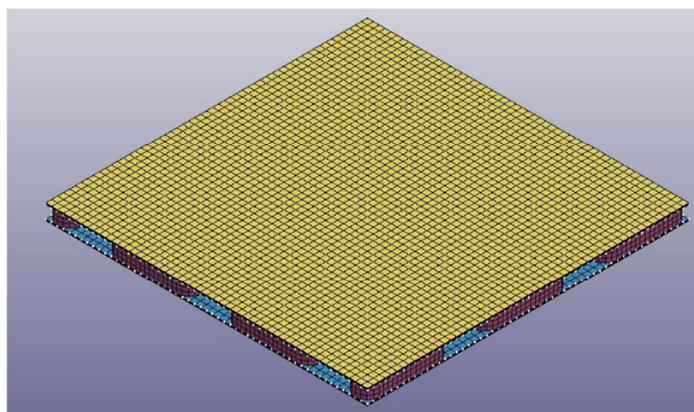


Fig. 3 - The finite element model

Table 1 - Material Properties

Material properties	ABSplus	Carbon/Epoxy
Moduli of elasticity (GPa)	E = 2.25	E <sub>1</sub> = 112.3 E <sub>2</sub> = 7.58
Density ( $\rho$ ) (g/cm <sup>3</sup> )	1.04	1.65
Poisson's ratio ( $\nu$ )	0.35	0.209
Yield strength ( $\sigma_y$ ) (MPa)	31	
Longitudinal compressive strength ( $\sigma_c$ ) (MPa)		1130
Longitudinal tensile strength ( $\sigma_t$ ) (MPa)		2070
Transverse compressive strength ( $\sigma_c$ ) (MPa)		61
Transverse tensile strength ( $\sigma_t$ ) (MPa)		205

Table 2 -Core Properties

Name	Core geometry	Core wall thickness ( $t_c$ ) (mm)
SP_1	Antitetrachiral	1
SP_2	Antitetrachiral	0.5
SP_3	Missing rib	1
SP_4	Missing rib	0.5

A uniformly distributed air blast load is applied on SP\_1, SP\_2, SP\_3 and SP\_4 plates. The air blast load is described by a Friedlander decay function. The peak pressure is taken as 30 kPa and the positive phase duration is 15 ms. The air blast load is shown in Fig. 4. The numerical analysis is achieved by using an explicit finite element solver.

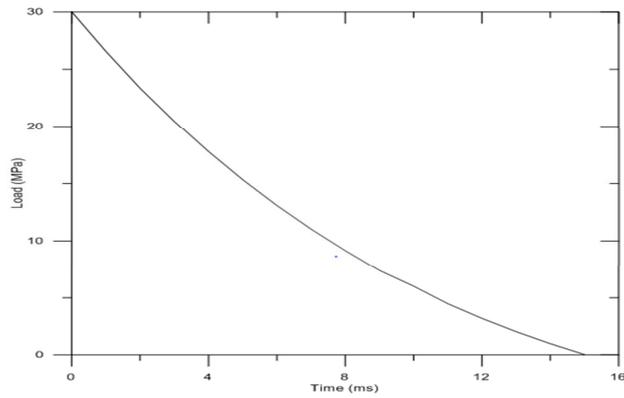


Fig. 4 - Air blast loading

## RESULTS AND DISCUSSION

It is observed that the plate vibrates under the applied load. The displacement time history of the center point on the top layer in the z direction, which is perpendicular to the plate surface, is shown in Fig. 5 for all sandwich plates considered here. It is shown that the displacement is decreased as the core wall thickness is increased. Therefore, it could be said that the stiffness of the sandwich plate is increased by increasing the core wall thickness.

The displacement in the z direction, the stresses in the x and y directions of the SP\_1 plate are given in Fig. 6 - Fig. 8 at the time that the displacement reaches the first peak point, respectively. It is observed that the maximum stresses do not exceed the strength of laminated face sheets. The von Mises stresses in the auxetic core of SP\_1 plate subjected to air blast loading is shown in Fig. 9 at the time that the displacement reaches the first peak point. It is observed that the von Mises stresses in the auxetic core is below the stresses occurring in the face sheets. This is because the modulus of elasticity of core is much lower than the modulus of elasticity of face sheets.

The displacement in the z direction, the stresses in the x and y directions of the SP\_3 plate are given in Fig. 10 - Fig. 12 at the time that the displacement reaches the first peak point, respectively. It is observed that the maximum stresses do not exceed the strength of laminated face sheets. The von Mises stresses in the auxetic core of SP\_3 plate subjected to air blast loading is shown in Fig. 13 at the time that the displacement reaches the first peak point. It is observed that the von Mises stresses in the auxetic core is below the stresses occurring in the face sheets.

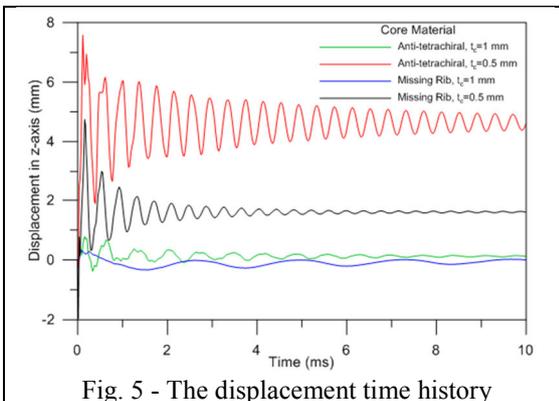


Fig. 5 - The displacement time history

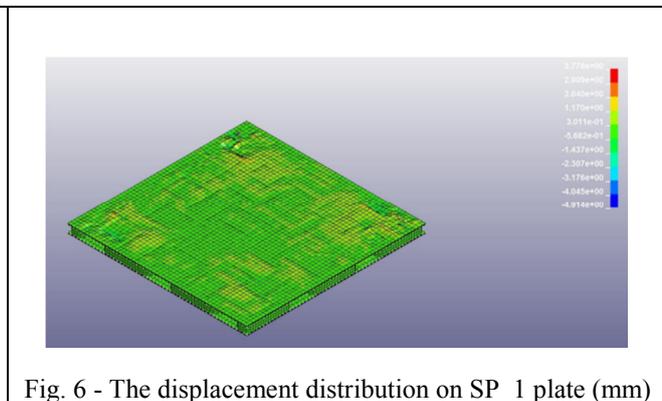


Fig. 6 - The displacement distribution on SP\_1 plate (mm)

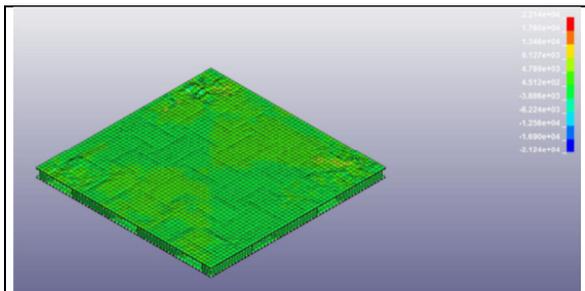


Fig. 7 - The stress distribution in the x direction on SP\_1 plate (MPa)

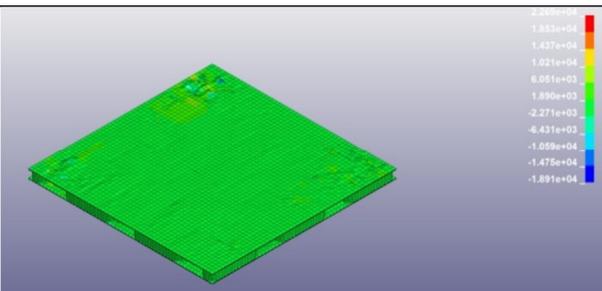


Fig. 8 - The stress distribution in the y direction on SP\_1 plate (MPa)

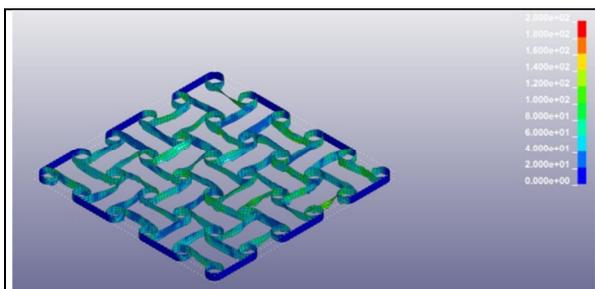


Fig. 9 - The von Mises stress distribution in core of SP\_1 plate (MPa)

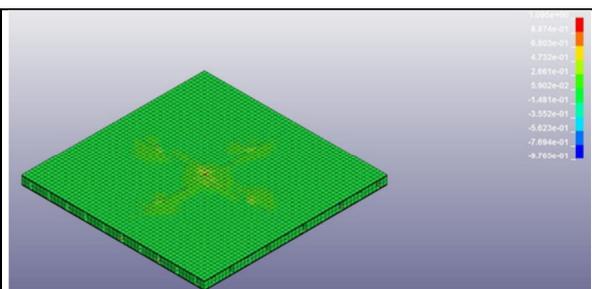


Fig. 10 - The displacement distribution on SP\_3 plate (MPa)

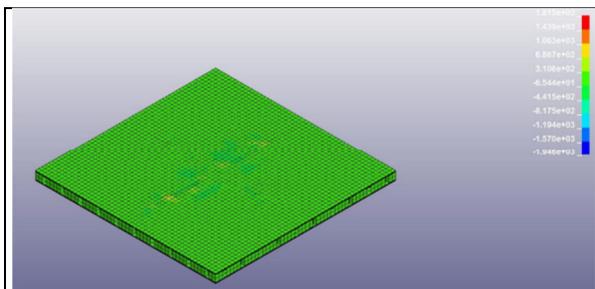


Fig. 11 - The stress distribution in the x direction on SP\_3 plate (MPa)

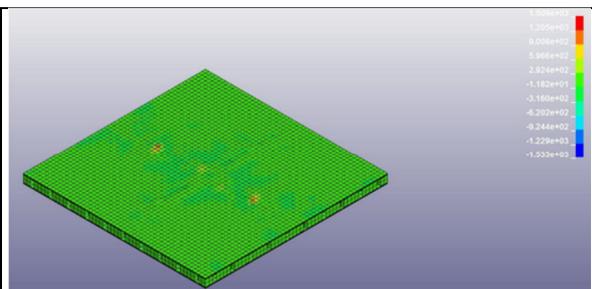


Fig. 12 - The stress distribution in the y direction on SP\_3 plate (MPa)

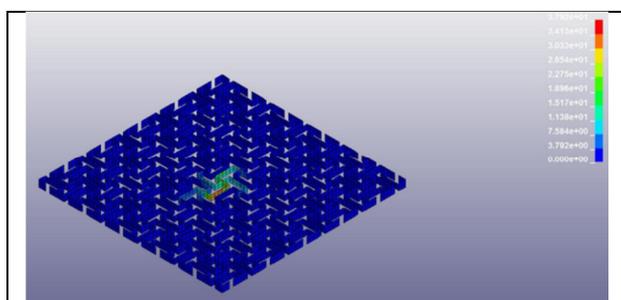


Fig. 13 - The von Mises stress distribution in core of SP\_3 plate (MPa)

## CONCLUSIONS

The displacement amplitude is decreased as the core wall thickness ( $t_c$ ) is increased for both auxetic shapes. The displacement in case of missing rib auxetic core is lower than that of antitetrachiral auxetic core. This is because the missing rib configuration considered in this study is denser than the antitetrachiral shape. The core wall thickness also has an important effect on the displacements. The displacement amplitude is decreased an important amount by increasing the core wall thickness. The midrange displacement value is also decreased as the core wall thickness is increased.

The stresses on the face sheets are almost uniformly distributed which indicates that the auxetic core contributes to transfer the load through the face sheet and the uniform load sharing (Fig. 7 and Fig. 8). The denser core (missing rib) contributes to uniform load sharing more than auxetic core which is less dense (Fig. 11 and Fig. 12). Stresses on the face sheets remained nearly constant during time because the midrange deformations are greater than the deformation amplitude for all sandwich plates considered in this study.

As mentioned above, maximum stress values remain nearly constant over the time. The lowest stress value is seen at the missing rib with 1 mm wall thickness. As the core wall thickness is reduced, stress value is increased.

The study showed that the some parameters, such as core cell density, core wall thickness and core shape, effect the overall plate dynamic behaviour. This provides us to design optimum sandwich plates with regard to the dynamic response.

## ACKNOWLEDGMENTS

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