NUMERICAL ANALYSIS OF COMPOSITE SANDWICH STRUCTURES WITH CIRCULAR HONEYCOMB CORE

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Abstract: In the article a sandwich structure with circular cells of honeycomb core is investigated in order to study the correlation between mechanical behaviour and weight for this structural model. A numerical model is built using Abaqus cae software to predict the out-of-plane elastic properties and the relative density of the honeycomb core, considering a unit cell as a Representative Volume Element (RVE) of the core. A parametric study is also performed to investigate the effects of cells' wall thickness and cells' radius on the overall mechanical behaviour of the honeycomb core. The maximum deflection and skin stresses for the entire sandwich structure are modelled using analytical equations. Then, the analytical solution is compared with Finite Element analysis. These results showed excellent agreement. The investigations showed that the honeycomb core unit cells' wall thickness and the cell's radius have a significant effect on the mechanical behaviour and the weight of the honeycomb core.

Keywords: sandwich structure; circular honeycomb core; FEM, unit cell, elastic properties

1. INTRODUCTION

Composite sandwich structures are often used in industries where a low weight-to-strength ratio is required, such as the automotive and aerospace industries. The design of these structures should reduce overall weight, lower fuel consumption and achieve higher stiffness. These considerations have long challenged researchers to develop further improvements for sandwich structures including face sheets separated by a core. The most common used core of the sandwich structures is the honeycomb core. Various configurations of honeycombs were fabricated and studied. The hexagonal honeycomb is inspired by the beehive and widely used in industry. Then, triangular, square and circular honeycombs were proposed depending on different

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polygonal variables. Liu et al. [1] studied the effects of honeycomb cell type and arrangement on energy absorption capacity. They simulated different arrangements of honeycombs under in-plane dynamic pressure. Tao et al. [2] analysed the regular hexagonal honeycomb with in-plane gradient characteristics in terms of energy absorption. Papka et al. [3] studied the in-plane compressive behaviour of a circular honeycomb specimens made of polycarbonate. FEM is an often used technique for analysis of structural elements [4,5]. Sun et al. [6] used FE simulation to investigate the in-plane impact behaviour of circular honeycomb. They considered a constant impact velocity from 1 to 250 m/s and determined a new mechanical term, the most appropriate strain, to evaluate the impact behaviour of such materials. Nian et al. [7] investigated the energy absorption capacity of a 3D-printed bionic graded circular honeycomb with a circular layout. They found that the stepped honeycomb has better energy absorption capacity.

In the article the investigation of the out-of-plane elastic properties and the relative density of the composite sandwich structures' circular honeycomb core is introduced. At first the Finite Element analysis for honeycombs' unit cell with composite cell walls is carried out by the application of the Abaqus cae software. After it analytical solution for the assembled sandwich structure are carried out to determine the homogenized properties of the honeycomb core analytically. Then, the analytical results are compared with the numerical simulation for verification.

2. FINITE ELEMENT MODEL FOR CIRCULAR UNIT CELL

The Representative Volume Element (RVE) can be defined as the smallest volume element for which the macroscopic constitutive representation is a sufficiently accurate model to represent the mean constitutive response [8]. Due to the complexity and computational cost of modelling entire structures, the RVE, which truncates the entire periodic structure, is a practical way to predict the homogenized properties of the structures. In the study the honeycomb unit cell was considered as the RVE with periodic boundary conditions. The RVE is modelled numerically using Abaqus software. Then, the prediction of the homogenized mechanical properties and relative density of the core is performed using the micromechanics plugin in Abaqus CAE.

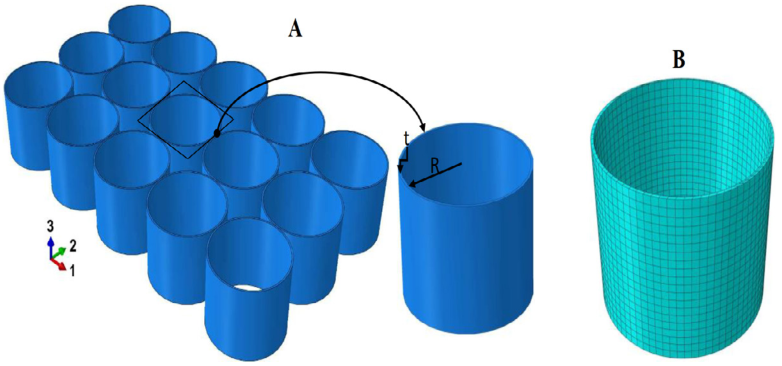


Fig. 1. Structure and unit cell of circular core

Fig.1-A shows the whole core and the truncated unit cell in 3D with the global coordinate system of the core (1, 2, 3). The FE model of the unit cell used to determine the out-of-plane elastic properties (G_{13}, G_{23}, E_{33}) and relative density by the micromechanics plugin is shown in Fig.1-B.

3. MECHANICAL PROPERTIES OF THE CIRCULAR CORE

Since the main function of honeycombs core is to provide sandwich structures with the required stiffness against the out plane loads at the lowest possible weight. The study focuses on the out plane elastic properties (i.e., E_{33} , G_{13}, and G_{23}) and to the relative density ($\overline{\rho}$), which reflects the core's weight. The honeycomb material is assumed to be aluminium with elastic modulus $E = 68200$ MPa, Poisson's ratio $\nu = 0.3$, and density $\rho_s = 2700$ kg/m^3. The parametric study is performed using the FE model developed in section (2). The cell radius (R) and the wall thickness (t) of the core cell are considered as design parameters with different values, showed in the Results section.

4. MODELING OF THE SANDWICH STRUCTURE

In this section, a rectangular, simply supported sandwich panel of size 2 × 1 m^2 subjected to a uniformly distributed normal load $P_0 = 0.001$ MPa is considered. The properties of the honeycomb core with design parameters $t = 0.1$ mm and $R = 3$ mm are used for analytical modelling of the sandwich panel. The sandwich face sheets have the same material as the core with thickness $t_s = 0.5$ mm and core thickness $t_c = 15$, 20, 25, and 30 mm. The detailed dimensions of the sandwich structure are shown in Fig. 2.

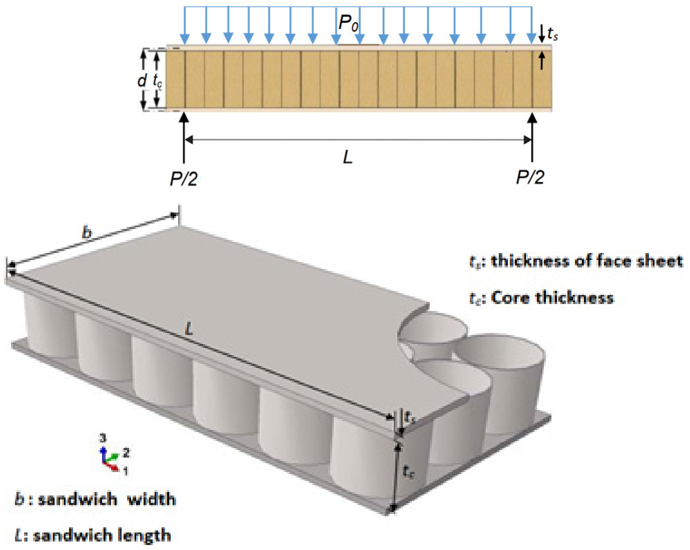


Fig. 2. Sandwich structure with circular honeycomb core

The analytical expressions can be formulated according to the reference [9].

- **Stress in the face sheets**

The stresses that occurred in the face sheets can be calculated as below:

$$\sigma_s = \frac{M}{d t_s b} \tag{1}$$

Where (d) is the distance between the centres of upper and lower face sheets and it can be calculated as below:

$$d = t_s + t_c \tag{2}$$

- **Deflection of the sandwich structure**

The total deflection of the sandwich structure includes the bending deflection and shear deflection:

$$\delta = \frac{k_b P L^3}{D} + \frac{k_s P L}{S} \tag{3}$$

Where $P = P_0 \cdot L \cdot b$, k_b = 5/384 and k_s =1/8 are equivalent load, bending deflection coefficient and shear deflection coefficient, the bending stiffness and shear stiffness can be calculated as below:

$$D = \frac{E_s t_s d^2 b}{2} \tag{4}$$

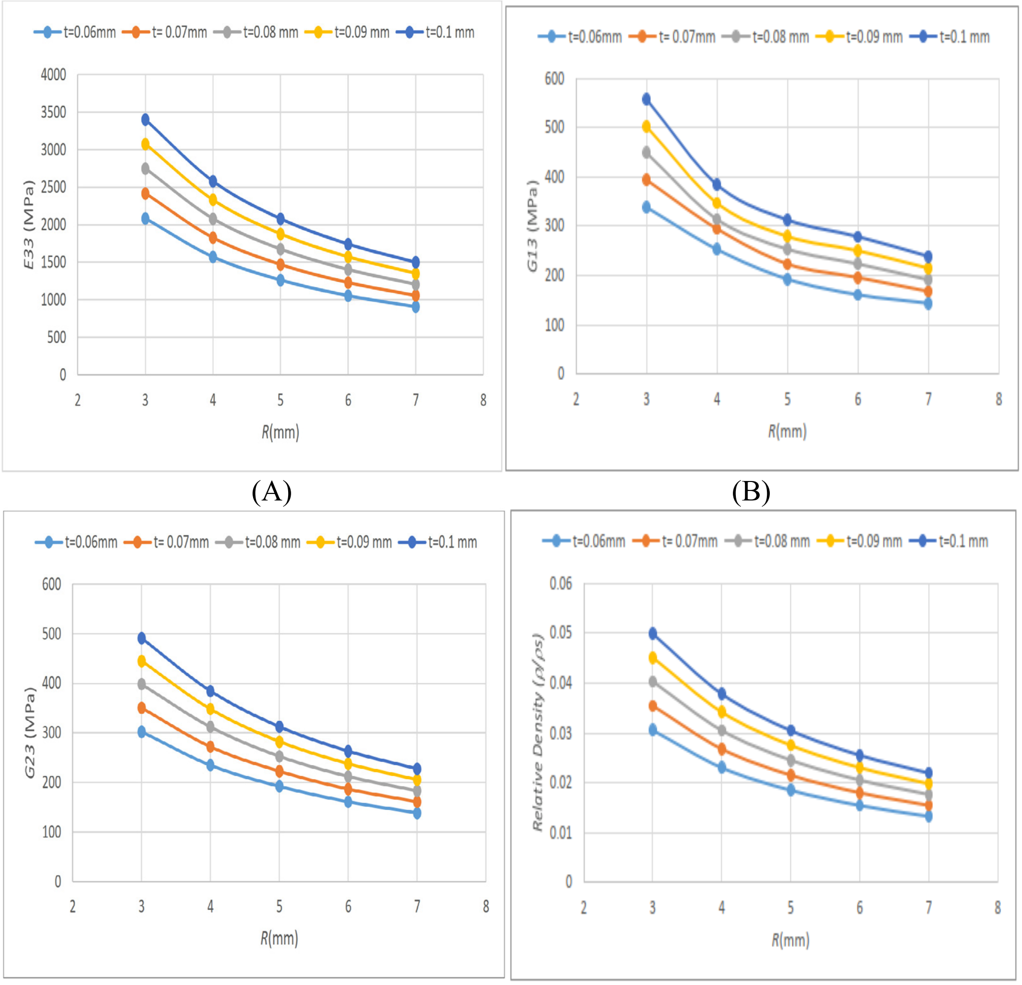
$$S = b d G_{13} \tag{5}$$

The analytical results are validated by FE modelling of the sandwich structure. Since FE modelling of the detailed core is computationally expensive, the honeycomb core is modelled as a solid layer characterized by homogeneous mechanical properties of the detailed honeycomb core [10,11]. The maximum deflection of the mid-plane of a simply supported sandwich structure is determined numerically and compared with the analytical results.

5. RESULTS

In this article, different designs of circular honeycomb cores were considered in terms of cell wall thickness (t) and cell radius (R). The elastic properties and relative density of the honeycomb core as a function of cell radius and wall thickness with values R = 3 - 7 mm and t = 0.06 - 0.1 mm are shown in Fig. 3 (A-D).

As we can see, the smaller radius of the honeycomb core cell leads to an improvement in the elastic properties of the honeycomb core (i.e. E_{33}, G_{13} and G_{23}). However, the improvement in the elastic properties comes at the expense of the relative density of the honeycomb core and thereby leads to a higher core weight, as can be seen in Fig. 3 (D). On the other hand, the thickness of the cell wall plays a key role in the mechanical properties and weight. A honeycomb core with a small thickness reduces the relative density of the core and leads to lighter cores. However, the mechanical properties of the honeycomb core deteriorated significantly with a thinner cell wall.



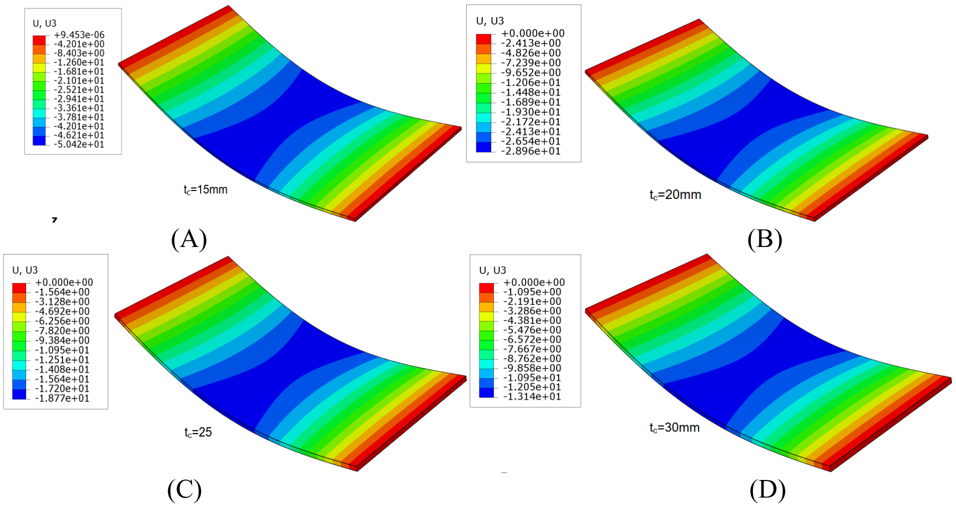
(A) (B)

(C) (D)

Fig. 3. The elastic properties of the honeycomb core

A Finite Element model is used to verify the analytical calculations of the sandwich model with core cell radius $R = 3$ mm and wall thickness $t = 0.1$ mm. The FE model considers the responses of the sandwich structure in terms of the maximum deflection of the sandwich structure and the stress in the face sheets (skins) for different values of the core thickness (t_c).

Fig. 4 (A-D) shows the results of the FE modelling in terms of the maximum deflection of the sandwich structure. It can be seen that the maximum deflection gradually decreases with increasing core thickness from t_c = 15 mm to t_c = 30 mm. This behaviour is due to the flexural stiffness of the sandwich structure, which increases with thicker honeycomb core.

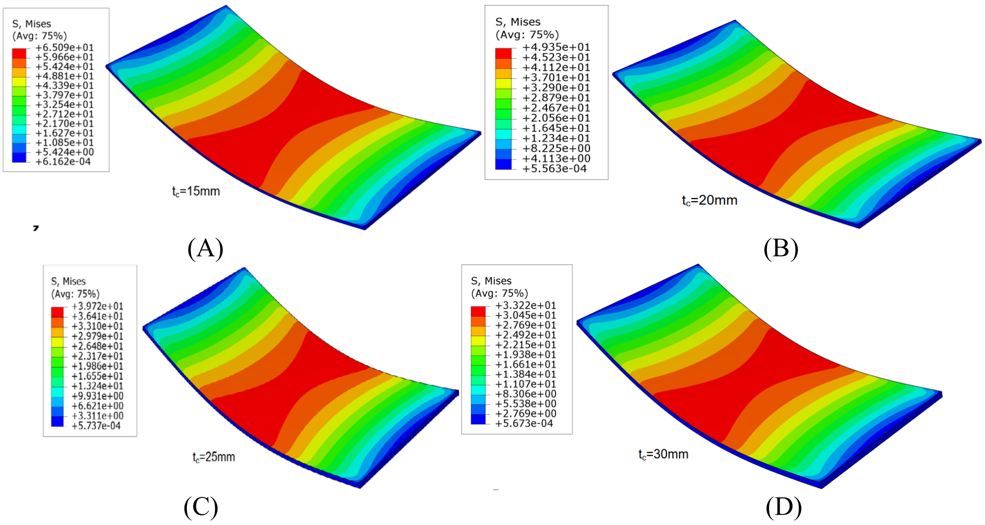


(A) (B)

(C) (D)

Fig. 4. Maximum deflection of the sandwich structure

Fig.5 (A-D) illustrates the FEM results of the stress distribution of the outer face sheets. The maximum stress of the outer face sheets decreases with increasing honeycomb core thickness, which is due to the fact that the stress in the outer face sheets is strongly correlated with the deflection of the sandwich structure.



(A) (B)

(C) (D)

Fig. 5. Maximum deflection of the sandwich structure

Therefore, a high flexural stiffness of the sandwich structure provides lower out-plane deflection and lower skin stresses. Table 1. shows clearly that the FEM outcomes are in good agreement with analytical solutions. This proves that the mechanical properties that predicted by RVE technique are reflected the properties of entire honeycomb core accurately.

Table 1. **Comparison of analytical and FEM results**

t_c (mm)	**Deflection** δ (mm)		**Skin Stress** σ_s (MPa)	
	Analytical	FEM	Analytical	FEM
15	50.92	50.42	64.52	65.09
20	29.12	28.96	48.78	49.35
25	18.83	18.77	39.22	39.72
30	13.16	13.14	32.79	33.2

6. CONCLUSIONS

This article presents an extensive investigation of the out-of-plane elastic properties of a composite sandwich structures' circular honeycomb cores. In the first part, the Finite Element model for honeycombs' unit cell with composite cell walls was established. The micromechanics tool in the Abaqus cae software was used to obtain the homogenized properties of the considered honeycomb core. The results showed that the elastic out-of-plane properties and relative density of the honeycomb core have strong correlation with the core's cell radius (R) and the cell's wall thickness (t).

In the second part, analytical solution for assembled sandwich structure was carried out to determine the homogenized properties of the honeycomb core analytically. Then, the analytical results were compared with the numerical simulation for verification. The results show that the Finite Element model has good agreement with analytical solution in terms of maximum deflection and stress distribution.

ACKNOWLEDGEMENTS

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