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HOMOGENIZATION OF ISOLATED HONEYCOMB CORE AND SANDWICH BY FINITE ELEMENT ANALYSIS AND CLASSICAL LAMINATION THEORY

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1. INTRODUCTION

Nomex honeycomb (HC) core is composed of Kevlar fiber paper impregnated by a phenolic resin organized in a periodic hexagonal cell structure. The macroscopic mechanical response of the HC core may be considered orthotropic or transversely isotropic with the principal directions, L, W and T. To simplify analysis of HC core sandwich, it is common practice to consider the honeycomb layer as an effective homogeneous solid that behaves as the actual HC core. This approach will by-pass the need for detailed structural analysis of the cell structure. Our main purpose of homogenization is to determine the effective in-plane extensional properties of the HC core. Such properties are essential for analysis of debonding failure. In homogenization analysis, the smallest representative part of the periodic honeycomb structure known as a unit cell is modeled. The main assumptions of homogenization are that the unit cell must be repetitive and small compared to the whole structure. A large number of studies have been performed to predict the effective mechanical properties of HC core. Gibson and Ashby [1] used beam analysis of HC core unit cells to determine equivalent in-plane and out-of-plane elastic properties. Malek et al. [2], and Masters and Evans [3] employed both analytical and numerical approaches to investigate the elastic behavior of periodic hexagonal honeycomb cores. Such studies have shown that isolated HC core has very large in-plane Poisson ratios. For a HC core bonded to two face sheets, it has been recognized that the in-plane deformation of the core is significantly constrained by face sheets [4-6]. This constraint causes an increase of the effective core stiffness compared to the unconstrained isolated core.

In this paper, homogenization analysis of isolated HC core and HC core bonded to face sheets is conducted using FEA. FE modeling of a representative volume element (RVE) is established. Extension of the analysis to HC core sandwich determines the interaction of core and face sheets.

2. GEOMETRY AND HOMOGENIZATION ANALYSIS

For a periodic structure like HC core, the smallest representative element is considered as the unit cell. In order to compare our results with previous analytical estimates [1], a single wall HC core is considered, see Fig. 1. The rectangular domain marked by dashed lines refers to the unit cell geometry. All cell walls have same wall thickness (h). Unit cell selection from the HC cores assembly results in eight wall blocks with two horizontal walls having half of the thickness (h/2).

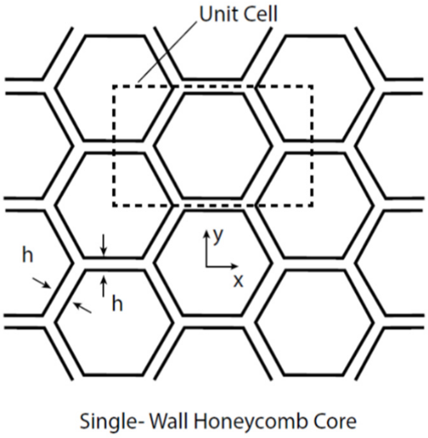
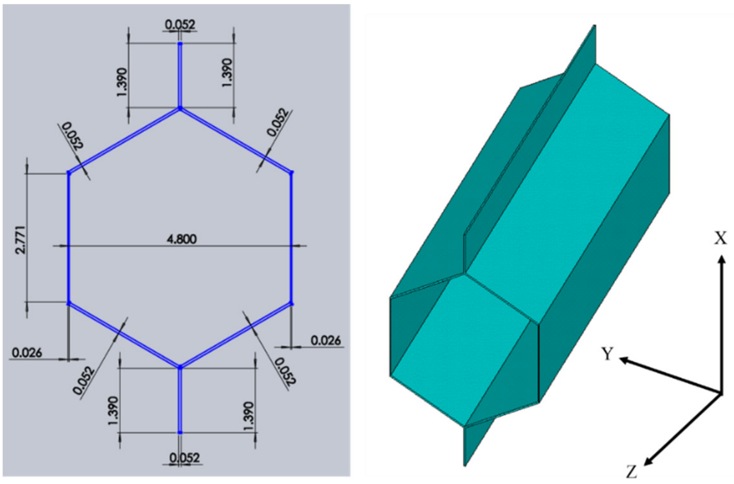


Fig. 1: HC core unit cell with single cell wall thickness.

Geometric models of isolated HC core and constrained HC core elements were created in FE program ANSYS v17.2 [7]. The HC core unit cell was modeled in both 2D and 3D, as shown in Fig. 2. All the corner angles are 120° and cell size is 4.80 mm. The height of the unit cell is 8.413 mm and the width is 4.852 mm (W- direction). The cell wall material is assumed to be isotropic with a Young's modulus (E) of 3.15 GPa and Poisson's ratio (v) 0.4. Projection of the 2D unit cell along the thickness (T) direction creates the 3D unit cell Fig. 2(b). The 3D unit cell is 12.7 mm in the thickness (T) direction, see Fig. 2(b). The HC core sandwich elements consists of two $0.052\ mm$ thick aluminum face sheets attached the 3D unit cell of HC core (Fig. 3(a)). The face material has $E = 70\ GPa$ and $v = 0.3$.

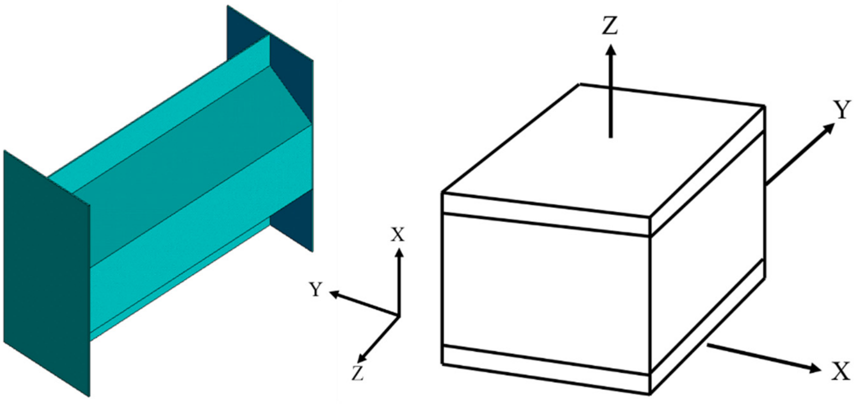


(a) (b)

Fig. 2: HC unit cell representations (a) two-dimensional (2D) (b) three dimensional (3D).

The 2D unit cell, Fig. 2(a), was meshed with 8 node Plane 183 elements configured in plane stress. The 2D model was discretized into a total of 2615 elements and 9809 nodes. For the 3D unit cell model, Fig. 2b, 20-node Solid 186 elements with reduced integration were used. The 3D unit cell was discretized into 51054 solid elements and 282022 nodes. To determine the effective in-plane modulus and Poisson ratio (E and v) in the x and y directions, displacement and constraints were imposed on the unit cells to represent uniaxial extension in the x and y directions, while fulfilling compatibility requirements.

Homogenization concept was also applied to the sandwich elements, Fig. 3. The effective in-plane properties (E_x and v_{xy}) of the structural core element, Fig. 3(a), were determined by imposing a x- axis displacement of the nodes on top edges while the corresponding nodes on the bottom edge were constrained in the x direction. Coupling degrees of freedom of nodes located on the unloaded surfaces, consistent with uniaxial loading in the x-direction and compatibility with neighboring cells were defined. Finite element analysis of a sandwich element with homogenized core was also conducted.



(a) (b)

Fig. 3: HC core sandwich elements a) FE model, b) laminate model.

The sandwich element consisting of two face sheets and homogenized core was also modeled by classical laminated plate theory (CLPT) as a three layer symmetric laminate. Fig. 3(b) shows the sandwich element considered. Assumption of plane stress in each layer ($\sigma_z = 0$) and analysis of a load case representative for extensional loading along the x-axis enables derivations of closed-form expressions for the effective in-plane properties of the sandwich [8].

3. RESULTS

The isolated HC core and the sandwich element were analyzed using the material properties and geometry of the constituents defined above. The effective elastic constants determined for the 2D and 3D unit cells of the isolated core element are listed in Table 1 along with predictions from Gibson and Ashby [1].

Table 1: Homogenized elastic properties (E and ν) for HC core.

Type	2D Unit Cell		3D Unit Cell	
	Young's modulus (MPa)	Poisson's ratio	Young's modulus (MPa)	Poisson's ratio
FEA	$E_x = 0.048$	$\nu_{xy} = 1.0$	$E_x = 0.048$	$\nu_{xy} = 1.0$
	$E_y = 0.048$	$\nu_{yx} = 1.0$	$E_y = 0.056$	$\nu_{yx} = 1.0$
Gibson-Ashby [1]	$E_x = E_y = 0.048$	$\nu_{xy} = 1.0$		

It is observed that the results predicted by Gibson and Ashby [1] are in very good agreement with our 2D FEA results. The results from the 3D analysis of the HC core similarly show good agreement with Gibson and Ashby predictions and the 2D FEA results. The 3D analysis provides similar results as the 2D analysis. Based on the results, it is concluded that the homogenization analysis based on 2D finite element approach provides a reasonable prediction of homogenized in-plane extensional stiffness properties of HC core.

The HC core sandwich was first analyzed by FEA with the actual HC core structure and a solid core with the homogenized properties obtained from 3D analysis (Table 2). E_x and ν_{xy} of the sandwich with orthotropic homogenized core was also determined by CLPT. Table 2 presents model results for the HC core sandwich. The results from all models are consistent.

Table 2: Effective properties of HC core sandwich.

Type	Young's modulus (MPa)	Poisson's ratio
HC Core Sandwich (FEA)	$E_x = 576$	$\nu_{xy} = 0.34$
	$E_y = 565$	($\nu_{yx} = 0.44$)
Homogenized Core Sandwich (FEA)	$E_x = 576$	$\nu_{xy} = 0.30$
CLPT	$E_x = 568$	$\nu_{xy} = 0.30$

Notice also the constraint imposed by the face sheets on the deformation of the core. The isolated core has Poisson ratio of 1.0, while the sandwich has Poisson ratio of about 0.3, similar to that of the face sheets.

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