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A numerical model for the honeycomb core sandwich panels in three-point bending by the homogenization method

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Abstract
Composite materials with their many outstanding advantages have become increasingly popular in many fields in engineering. In the use of composite material, the proper use of the structure also brings great efficiency. To use materials effectively, understanding their mechanical behavior is essential therefore, the calculation to determine their mechanical behavior is very necessary. The calculation with composite material structures has been mentioned by many authors, but with large, unsymmetrical sandwich panels, these methods are still very difficult. In this paper, we present a method to build an equivalent model for the honeycomb core sandwich (3D-Solid model) that can be used to determine the mechanical behavior of sandwich panels instead of the original model (3D-Shell model). This work helps to significantly reduce the computational time as well as time to build the geometry of the model. This homogeneous model is confirmed by comparing the finite element simulation results of the three-point bending test for both models.
Keywords: *Sandwich panel, Honeycomb plate, Homogenization, Finite element*

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I. INTRODUCTION

Nowadays, material engineering plays a pioneering role in many fields of science and technology. In the use of material, the proper use of the structure also brings great efficiency. Sandwich panels are often formed by adhering to two high-density thin plates called face sheets with a low-density core possessing less strength and stiffness. We can obtain various properties and desired performances, especially high strength to weight, by varying the core materials, core structures and core thickness, or material of face sheets. Many different core shapes have been applied to the construction of sandwich structures as corrugated, solid, foam. Honeycomb sandwich panels are widely used because they provide a good compromise between stiffness and lightness. Recent advances in materials and manufacturing techniques as well as the continued development of technology have led to improvements and increased uniformity of the properties of sandwich composites. The optimal design of the sandwich structure is the primary goal that needs to be achieved. Currently, the optimal design of the sandwich has the effective help of the computer. Creating CAD models and finite element analysis for the details of these structures has become easier than in the past [1]. However, there are still major challenges such as the complexity of structures, large computation time, and memory requirements of mainframes. So far, many researchers have used different homogenous models or equivalence models to overcome this difficulty [2–11]. With the specific geometry and complex conditions in the honeycomb structure, the analytical method is always effective. It is proven by a homogenization model based on the integral method, which has been successfully applied to complete structures with complex cores such as corrugated boxes and the honeycomb core sandwich panels in the case tensile [12,13,14]. In this work, we propose a homogeneous method to build a numerical model for sandwich panels. This is done by calculating the in-plane properties for the 3D shell structure of the honeycomb core and it is then replaced by an equivalent homogeneous 3D solid core. Numerical simulation of three-point bending tests performed for homogeneous core plate and 3D shell core plate. The results show that the 3D-solid homogeneous model has close results with the 3D-shell model, while computation time and model preparation time are greatly reduced.

II. HOMOGENISATION METHOD

Using the full 3D model to calculate the in-plane properties of the honeycomb core sandwich panels consumes a lot of time. To reduce the preparation of the model and the computational times, we have developed a homogenization model for the honeycomb core sandwich panels. This homogenization method is the use of a homogeneous fictional material with equivalent macroscopic properties in place of the heterogeneous real material of the 3D-shell structure of the core. We consider a Representative Volume Elemental (RVE) as shown in Fig.1.

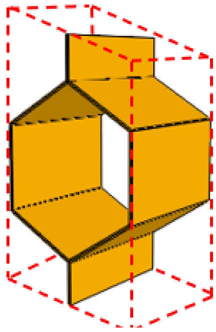

Figure 1. RVE for honeycomb core

Accordingly, the tensile properties are determined on a single honeycomb cell without the influence of the skin layers and the properties depend only on the bending behavior of the honeycomb walls. Thus, we can calculate the elastic modulus E_x and E_y by computing displacements in the x and y directions [8]. In this method, it is assumed that the skin is very stiff relative to the core of the honeycomb and the deformation of the honeycomb wall will be determined by the skin layers [15], the effect of tensile or compressive forces of the thin walls will govern their bending effect. Based on classical homogenization theory and recent research results [8,16–20], the calculation procedure of this homogenization method is:

2.1. Calculate Young's modulus E_x

From the REV model, we construct the internal force equation on the five walls EA, AC, CB, CD, and DF. Performing the displacement at the center of the core from h/2 to the end position for points A, C, and D, we have an equivalent structure as presented in Fig.2. At this point A and B are fixed on the skin; The problem to be determined is what force must be applied at D to get the displacement $u_0 = 1$. We have:

$$\varepsilon_x = \frac{u_0}{2l\cos\theta} \quad ; \quad \varepsilon_y = \frac{v_0}{h + l\sin\theta} = -\nu\varepsilon_x = -\nu\frac{u_0}{2l\cos\theta} \tag{1}$$

$$\Rightarrow v_0 = -\nu u_0 \frac{h + l\sin\theta}{2l\cos\theta} \tag{2}$$

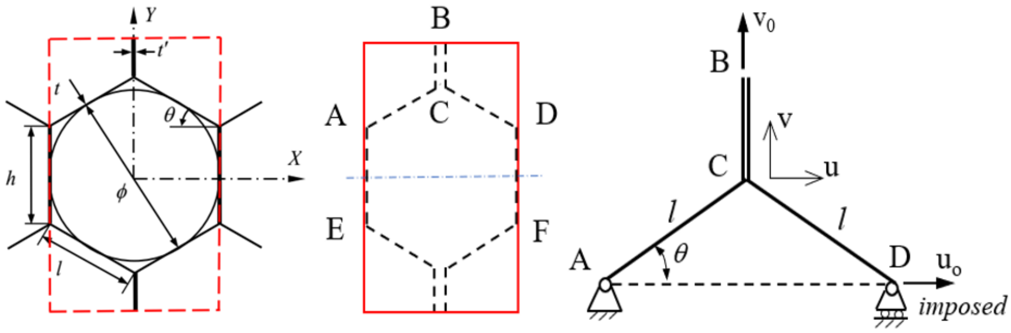

Figure 2: Model for calculating elastic modulus E_x for an RVE of honeycomb core

$$\varepsilon_l = \frac{1}{l}(u\cos\theta + v\sin\theta) \tag{3}$$

$$N_l = \sigma_l.b.t = \frac{Ebt}{l}(u\cos\theta + v\sin\theta) \tag{4}$$

$$N_h = E\frac{v_0 - v}{h}.2.bt \tag{5}$$

Considering the equilibrium of the node at C, we have:

$$N_h = 2N_l\sin\theta \tag{6}$$

From (4), (5), and (6), we have:

$$\frac{2Ebt}{h}(v_0 - v) = 2\sin\theta\frac{Ebt}{l}(u\cos\theta + v\sin\theta) \tag{7}$$

$$\Rightarrow l(v_0 - v) = h\sin\theta(u\cos\theta + v\sin\theta) \tag{8}$$

Another way:

$$u = \frac{1}{2} u_0 \quad ; \quad v_0 = -\nu u_0 \frac{h + l \sin\theta}{2l\cos\theta} \tag{9}$$

$$\Rightarrow v = \frac{v_0 - \dfrac{h}{4l}\sin^2\theta . u_0}{1 + \dfrac{h}{l}\sin^2\theta} \tag{10}$$

We have:

$$P_x = N_l \cos\theta = \frac{Ebt}{l}\left(u\cos\theta + v\sin\theta\right)\cos\theta \tag{11}$$

$$E_x^* = \frac{\sigma_x^*}{\varepsilon_x^*} = \frac{P_x}{\left(h + l\sin\theta\right)b} . \frac{2l\cos\theta}{u_0} \tag{12}$$

From Eq. (11) and (12), we have:

$$E_x^* = \frac{2E.b.t\left(u\cos\theta + v\sin\theta\right).\cos^2\theta}{\left(h + l\sin\theta\right)b.u} \tag{13}$$

2.2. Calculate Young's modulus E_y

For the case traction, a displacement along the y-direction $v_0 = 1$ is imposed:

$$\varepsilon_y = \frac{v_0}{h + l\sin\theta} \quad ; \quad \varepsilon_x = \frac{u_0}{2l\cos\theta} = -\nu\varepsilon_y = -\nu\frac{v_0}{h + l\sin\theta} \tag{14}$$

$$\Rightarrow u_0 = -\nu . v_0 \frac{2l\cos\theta}{h + l\sin\theta} \tag{15}$$

$$\varepsilon_l = \frac{1}{l}\left(u\cos\theta + v\sin\theta\right) \tag{16}$$

From Eq. (7), we have:

$$v = \frac{v_0 - \dfrac{h}{2l}\sin\theta\cos\theta . u_0}{1 + \dfrac{h}{l}\sin^2\theta} \quad ; \quad u = \frac{1}{2}u_0 \tag{17}$$

On the other hand, we have:

$$P_y = N_h = \frac{2\,\mathrm{Ebt}}{h}\left(v_0 - v\right) \tag{18}$$

$$E_y^* = \frac{\sigma_y^*}{\varepsilon_y^*} = \frac{P_y}{\left(2l\cos\theta\right)b} . \frac{h + l\sin\theta}{v_0} \tag{19}$$

From Eq. (18) and (19), we have:

$$E_y^* = \frac{\sigma_y^*}{\varepsilon_y^*} = \frac{E.2tb\left(v_0 - v\right)}{\left(h.2l\cos\theta\right)b} . \frac{h + l\sin\theta}{v_0} \tag{20}$$

For sandwich plates with very small core heights, we will use the Poisson's ratio like the Poisson's ratio of two skins. However, if the plate has a large core height, we can use Gibson's formula to calculate the Poisson's ratio:

$$\nu_{yx} = \frac{\left(\dfrac{h}{l} + \sin\theta\right)\sin\theta}{\cos^2\theta} \tag{21}$$

$$\nu_{xy} = \frac{\cos^2\theta}{\left(\dfrac{h}{l} + \sin\theta\right)\sin\theta} \tag{22}$$

2.3. Calculate Young's modulus E_z

The elastic modulus E_z is calculated by multiplying the modulus E_s of the honeycomb core by the ratio [3]:

$$E_z^* = E_t \frac{4ht + 4ht}{\left(2h + 2l\sin\theta\right)2l\cos\theta} = E_t\left(\frac{t}{l}\right)\frac{h + l}{\left(h + l\sin\theta\right)\cos\theta} \tag{23}$$

Poisson's coefficients ν_{zx} and ν_{zy} are assumed to be equal to the Poisson's ratio ν_{12} of the paper layer forming the honeycomb core, that is:

$$\nu_{zx} = \nu_{zy} = \nu_{12-core} \tag{24}$$

The reciprocal relationship allows to determine the remaining 2 Poisson's ratios:

$$\nu_{xz} = \frac{E_x}{E_z}\nu_{zx} \tag{25}$$

$$\nu_{yz} = \frac{E_y}{E_z}\nu_{zy} \tag{26}$$

2.4. Calculate shear modulus in the plane G_{xy}

For in-plane shear, we impose a shear angle γ, so tensile and compression deformation will occur in two inclined walls, we have:

$$\gamma = \frac{u_1}{\frac{h}{2}} = \frac{u_2}{\frac{h}{2} + l\sin\theta} \tag{27}$$

$$\Rightarrow \varepsilon_s = \frac{(u_2 - u_1)\cos\theta}{l} = \frac{l\sin\theta.\gamma.\cos\theta}{l} \tag{28}$$

On the other hand, we have:

$$\sigma_s = E_s.\varepsilon_s = E_s.\gamma.\sin\theta\cos\theta \quad \& \quad T_x = \sigma_s.2.t.b.\cos\theta \tag{29}$$

For a homogeneous solid core, we have:

$$\tau^*_{xy} = G^*_{xy}\gamma \Rightarrow G^*_{xy} = \frac{\tau^*_{xy}}{\gamma} = \frac{T_x}{2l\cos\theta.b.\gamma} \tag{30}$$

Replace (29) with (30) we have:

$$G^*_{xy} = E_s\left(\frac{t}{l}\right)\sin\theta\cos\theta \tag{31}$$

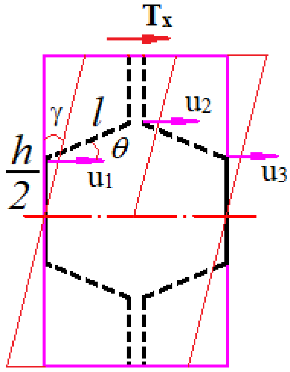

Figure 3: Calculation model of shear modulus G_{xy} for an RVE

III. NUMERICAL VALIDATION OF THE HOMOGENIZATION MODEL

The three-point bending tests, by finite element simulations, are performed for the 3D-shell structure of the sandwich plate and the homogenized 3D-solid sandwich plate to validate our proposed homogenization 3D-Solid model. According, the sandwich panel is placed on two steel supports, the force is applied (F=100kN) through the roller in the middle (Fig.4). Two plates with the same length (L = 220 mm) and width (B = 80 mm). For the skin and the core of the 3D-shell sandwich plate, the mechanical properties are given in Table 1 and Table 2. By using a homogeneous method, we calculated the mechanical properties of the core for the homogenized 3D-solid sandwich plate as shown in Table 3.

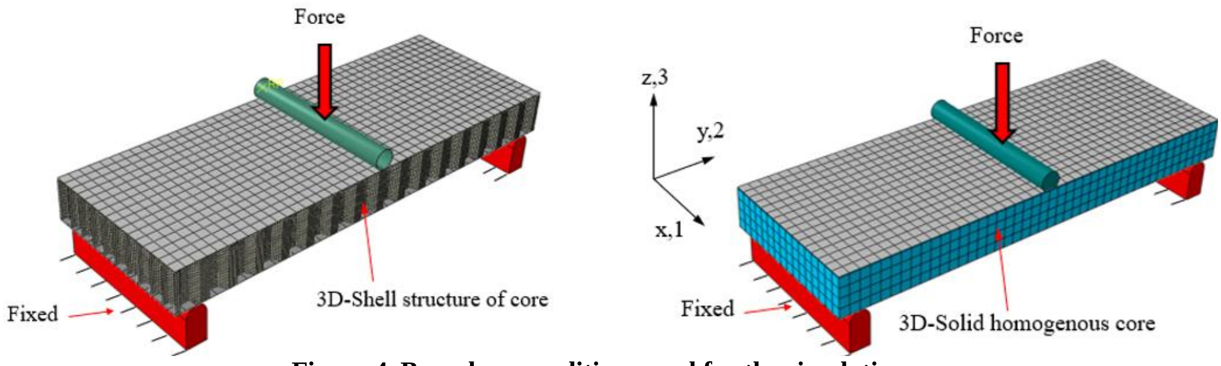

Figure 4. Boundary conditions used for the simulations

Table 1: Parameters of the layers forming the skins of honeycomb core sandwich plate

E_1 (MPa)	E_2 (MPa)	ν_{12}	G_{12} (MPa)	G_{13} (MPa)	G_{23} (MPa)	Thickness (mm)
18000	2000	0.4	8500	10	10	0.2

Table 2: Parameters of the paper forming the honeycomb core of the sandwich plate.

E_1 (MPa)	E_2 (MPa)	ν_{12}	G_{12} (MPa)	G_{13} (MPa)	G_{23} (MPa)	Thickness (mm)
3292	1594	0.42	788	10	10	0.19

Table 3: Parameters of the paper forming the honeycomb core of the sandwich plate

ϕ (mm)	θ (°)	l=h (mm)	t (mm)	t' (mm)	Height (mm)
8	30	4.62	0.19	0.38	20

The 3D-shell plate mesh with reduced-integration four-node shell elements (S4R) with 98788 elements and 99214 nodes. The 3D-solid plate mesh with reduced-integration four-node shell elements (S4R) with 1408 elements and 1530 nodes for the skins, 2816 solid elements C3D8R with 3825 nodes for the solid core. The obtained results are presented in Table 4 and Fig.5. It is easy to see that calculations using 3D-shell calculations take a lot of time, while 3D-solid models are very fast. The deviation of the maximum displacement of the two models is less than 0.5%, while the CPU time is reduced by more than 30.84 times for the 3D-solid model. Therefore, in computation by finite element simulation, the proposed homogenous model can be used to replace the 3D-shell model.

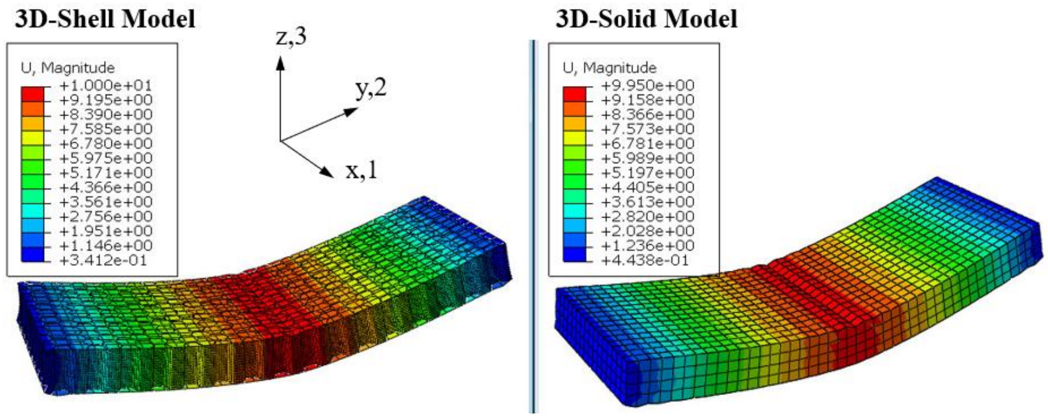

Figure 5. Simulation of 3D-Shell model and 3D-Solid model in three-point bending

Table 4. Comparison between Abaqus-3D and H-2D-Model for the plate under traction, flexion, and in-plane shear loading

	3D-Shell Model	3D-Soled Model	Relative difference
Displacement (mm)	10	9.95	0.5%
CPU time (s)	425.7	13.8	- 30.84 times

IV. CONCLUSION

In this study, we have proposed a homogenization method to calculate the honeycomb core of a sandwich panel. Using this method, we have built a 3D-solid model. This model is proven to reduce computation time and the preparation time for the CAD model. The comparison of the obtained simulation results from two models allows evaluating the efficiency and accuracy of the proposed homogenous model. This model applies to the different honeycomb core sandwich panels

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