PAMM · Proc. Appl. Math. Mech. **10**, 403 – 404 (2010) / **DOI** 10.1002/pamm.201010194

Application of Homogenization FEM Analysis to Aluminum Honeycomb Core Filled with Polymer Foams

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The effect of polyvinyl chloride (PVC) foam filler on elastic properties of a regular hexagonal aluminum honeycomb core is studied. The unit cell strain energy homogenization approach based on the finite element method (FEM) within ABAQUS code is applied for prediction of effective material constants of the foam-filled honeycomb core. The developed FE model is then used to observe a three-dimensional stress state over the hexagonal unit cell and, thereby, to assess the influence of the foam-filling on the distribution of the local interfacial stresses.

1 Introduction

Composite sandwich materials are very attractive than traditional ones in aerospace and aircraft applications due to their advanced properties. At the same time sandwich structural components can be easily damaged. Recent studies show that a filling of honeycomb structures with a foam may be used as a reinforcement of honeycomb-cored sandwich material systems [1, 2]. This method is inexpensive and does not add a significant amount of weight to the sandwich structure. However, the foam filler existence within honeycomb cells improves not only damage tolerance of the structure, but changes its responses. Hence, there is a need to gain insight into behaviors of foam-filled sandwich constructions. In order to attain efficiency of numerical simulations in engineering practice, the actual cellular structure of the honeycomb core is usually replaced by an equivalent homogeneous anisotropic medium with effective elastic properties [3]. This gives the opportunity to use shell or solid elements for modelling the honeycomb core in the three-layered arrangement of sandwich constructions. On the other hand, the reliability of the continuum model strongly depends on the accuracy of the effective core properties. Thus, the prediction of the effective properties of the honeycomb core materials should be performed as exactly as possible.

2 Finite Element Modelling

The cellular properties of the foam-filled aluminum honeycomb core are converted to effective out-of-plane and in-plane continuum ones by using the FE model developed with ABAQUS [4]. The representative part of the cellular core called a unit cell is modelled with a combination of shell and solid elements. An 8-noded second-order shell element `S8R5` with reduced integration was selected to model the unit cell walls. The isotropic material model for the element, corresponding to the properties of the honeycomb parent foil material, was assigned (Table 1). While, a 20-noded brick element with a parabolic basis function `C3D20R` was used to model the core foam material. A reduced integration element formulation was adopted to avoid a volumetric locking. Isotropic material model was taken for the PVC foams (Table 1). The coupling between shell and solid elements in the FE mesh is achieved by the constraint of redundant DOFs in coincident nodes, where these elements have been contacted. Due to symmetric nature of the unit cell only one-quarter of its full size with boundary conditions accounting for the symmetry was considered. Single wall thickness was used for the model, since the double thickness walls in the ribbon direction are on the split line of the repeating unit cells. Moreover, to take into account the skin effect, the in-plane core properties were studied basing on the constrained model.

Table 1 Elastic properties of constituent materials.

Foil material	Aluminum 5052 alloy	$E = 72$ GPa, $\rho = 2770$ kgm^{-3}, $\nu = 0.31$
Filler material	H grade PVC foams [5]	H 60: $E = 0.056$ GPa, $\rho = 60$ kgm^{-3}, $\nu = 0.27$; H 100: $E = 0.105$ GPa, $\rho = 100$ kgm^{-3}, $\nu = 0.32$; H 200: $E = 0.230$ GPa, $\rho = 200$ kgm^{-3}, $\nu = 0.32$

Six independent loading cases corresponding to the conditions of the mechanical tests to find appropriate engineering constants such as E_x, E_y, E_z, G_{xz}, G_{yz} and G_{xy} were featured by six types of displacement boundary conditions. The effective moduli were computed by using the strain energy, U, stored inside the unit cell for the each deformed state as the following: $C^{eff} = \frac{2U}{\varepsilon_{eq}^2 V}$, where ε_{eq} is the equivalent homogeneous strain corresponding to the imposed displacement fields and V denotes the volume of the homogeneous material block equivalent to the honeycomb unit cell.

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	E_x	E_y	E_z	G_{xy}	G_{xz}	G_{yz}	ρ
				MPa			kgm^{-3}
AlH	0.430	0.430	1493	0.108	341.1	205.4	57.17
FfH60	0.672	0.672	1549	0.238	356.2	212.1	101.95
FfH100	0.788	0.788	1598	0.282	374.3	224.4	141.31
FfH200	1.061	1.061	1722	0.386	422.1	238.9	170.83

Table 2 Effective elastic properties of the foam-filled honeycomb core materials.

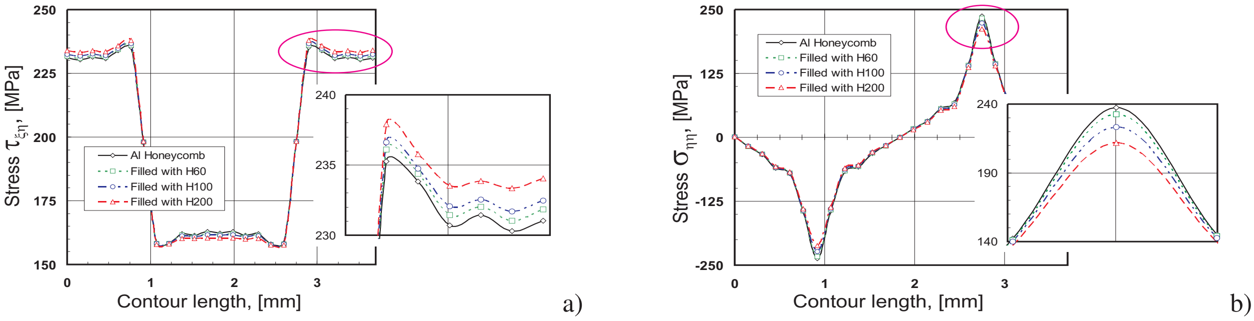

Fig. 1 Interfacial stress distributions along the top face of the cell walls for the hollow and filled with the different foams honeycomb structure subjected to $\gamma_{xz} = 0.01$: **a**) the shear stress $\tau_{\eta\xi}$; **b**) the normal stress $\sigma_{\eta\eta}$.

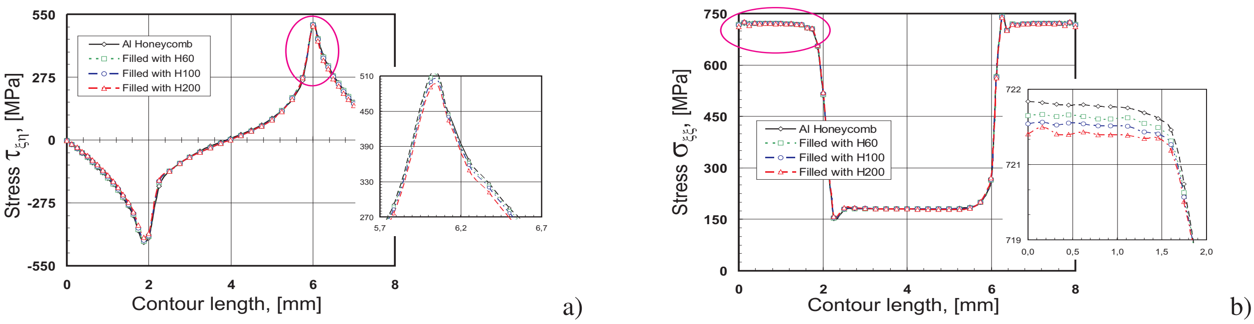

Fig. 2 Interfacial stress distributions along the top face of the cell walls for the hollow and filled with the different foams honeycomb structure subjected to $\varepsilon_{xx} = 0.01$: **a**) the shear stress $\tau_{\eta\xi}$; **b**) the normal stress $\sigma_{\xi\xi}$.

The hexagonal honeycomb core (AlH) with thickness equal to 5 mm and made of aluminum alloy foil with thickness of 0.0254 mm and cell size of 3 mm filled with the PVC foams (Ff) of various densities was studied. The influence of the PVC foam fillers on the effective elastic constants of the honeycomb core is shown in Table 2. As it follows from the results obtained the foam filling of the honeycomb structure causes more significant strengthening in-plane properties of the sandwich core than its out-of-plane ones. The effect of the PVC foam fillers on distributions of the interfacial stresses in the case of the pure shear strain state $\gamma_{xz} = 0.01$ is shown in Fig. 1. One can see from Fig. 1a that the interfacial shear stress $\tau_{\eta\xi}$ slightly increases on the flat cell walls, while it insignificantly decreases on the inclined cell wall with increasing of the foam density. Fig. 1b shows that the foam-filling decreases the magnitude of the peel interfacial stress $\sigma_{\eta\eta}$ associated with the warping effect at the critical section of the unit cell. The positive, from a strength viewpoint, foam-filling influence on the distribution of the interfacial shear $\tau_{\eta\xi}$ and normal $\sigma_{\xi\xi}$ stresses under imposed the tension strain $\varepsilon_{xx} = 0.01$ is shown in Fig. 2. One can see that the presence of the foam filler within the honeycomb cell slightly decreases the peak values of these interfacial in-plane stresses. Thus, the interfacial stress distributions along the top face of the flat and inclined cell walls (contour length) allow to conclude that foam-filling causes small reduction of the maximum magnitudes of the interfacial stresses at the critical section located at the intersection of the cell walls and, as consequence, leads to more uniform stress-state within the cell walls. These effects are magnified by the density of the filling foams.

Acknowledgements This research was supported by European Union within the project CEMCAST FP-245479.

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