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Role of different fiber orientations and thicknesses of the skins and the core on the transverse shear damping of polypropylene honeycomb sandwich structures

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ABSTRACT

This paper investigates the effect of different orientations of fiber in the skins and different thicknesses of the skins and polypropylene honeycomb core (PPHC) on the transverse shear damping of the sandwich using experimental and theoretical studies. Three different sandwiches, SW1 (thickness of top and bottom FRP skin: 3.15 mm each with 10 mm thick PPHC), SW2 (thickness of top and bottom FRP skin: 1.575 mm each with 5 mm thick PPHC), SW3 (thickness of top and bottom FRP skin: 1.575 mm each with 10 mm thick PPHC) were fabricated for conducting experimental work. In order to study the effect of fiber orientation of the skin on the natural frequency and loss factors, five different orientations (all 0°, ±30°, ±45°, ±60° and all 90°) were considered. An impulse technique was used to calculate the natural frequency and loss factor of the composites. The natural frequency and loss factor were also computed theoretically and compared. As the in-plane load of the strong FRP skins imposes on the soft honeycomb core under dynamic condition, it causes a large transverse shear deformation on the core. This shear deformation leads to a high energy dissipation/loss factor of the sandwich. At the 0° fiber oriented sandwich, the loss factor value (η = 0.0234) becomes significantly higher without losing its natural frequency (stiffness) value (f_n = 142.12 Hz), which is not so in the case of FRP composites having the loss factor (η) value of 0.00218 and the natural frequency value (f_n) of 114.23 Hz. It is also found that the transverse shear effect and damping loss factor increases with the increase in the thicknesses of the skins and core of the sandwich.

1. Introduction

Fiber reinforced polymer (FRP) composites are commonly used in automotive, aerospace, marine, and civil structures applications. Damping is an essential property of the structures when vibration control is critical to extend the service life of the structures. There are many types of damping or energy dissipation methods like active and passive (material or system) damping (Trindade and Benjeddon, 2002) and aerodynamic damping, viscous damping (Zhang et al., 2011) etc. This paper is confined to the material damping of the polymeric composite materials which can also be termed as passive damping. The damping loss factor of the polymer matrix composite (PMC) materials is about 10 to 100 times greater than that of the structural metallic materials (Yang et al., 2013). It is

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due to the dissipation of energy by the visco-elastic behavior of the matrix, the fiber–matrix interface, and damage. It is also influenced by the visco-elastic layer properties (Yim et al., 2003; Meaud et al., 2013) as well as the layer orientations (Adams and Maheri, 1994), interface (Chandra, 2003), temperatures (Youssef and Berthelot, 2006; Jen and Lin, 2013), etc. The influence of all these parameters on the damping loss factor of PMC was studied by Ni and Adams (1984), Adams and Maheri (1994), Yim (1999), Yim and Gillespie (2000) and Remillat (2007). However, the studies to demonstrate the above mentioned factors on the damping loss factor of the honeycomb sandwich FRP composites have been limited. The use of a honeycomb material in a composite laminate is witnessed in aerospace structures, where weight reduction and high flexural rigidity constitute the primary concern in designing structures (Bassani et al., 2013; Wang and Yang, 2000). The FRP composite has a high in-plane stiffness-to-weight ratio, whereas the honeycomb sandwich possesses a high bending stiffness-to-weight ratio, in addition to the high in-plane stiffness to weight ratio (Maheri et al., 2008).

As the present study focuses on the modal characteristics of polypropylene (PP) honeycomb sandwich panel, many papers related to this domain have been reviewed. Adams and Maheri (1993) have studied the variation in the specific damping capacity (SDC) with respect to shear stress amplitudes for aluminum and Nomex honeycomb sandwiches and reported that a sound honeycomb sample would experience linear damping at low stress amplitudes. The contribution of the different constituent parts in the aluminum honeycomb sandwich construction on the damping property has also been investigated by Maheri and Adams (1994) under flexural loading conditions. The findings have demonstrated a high degree of interdependence between the skins and the core, contributing to the overall damping. More recently, they (Maheri et al., 2008) have used the basic laminate theory, together with the Rayleigh–Ritz method, the finite element analysis and the experimental method, to predict damping and frequency of the honeycomb sandwich for space applications and considered the inherent damping of aluminum and carbon fiber-reinforced plastic (CFRP) skins in sandwich panels. The damping effect of sandwich beams was also experimentally investigated with fine solder balls inserted in the honeycomb cells, losing the advantage of its lightweight (Wang and Yang, 2000). It was found that the damping was quite effective on measuring the reduction in amplitude from the first two modes of vibration.

Yim et al. (2003) have studied the in-plane and transverse damping effect of 0° laminated composite sandwich cantilever beams with interleaving of a solid visco-elastic layer. They have also predicted the variation in the loss factor with the aspect ratio (length/thickness) of composites. Jung and Aref (2003) have combined the solid visco-elastic material with a polymer honeycomb material and studied the damping behavior under different strain and frequencies inputs. The interleaving of both the materials was expected to improve the stiffness and the energy dissipation capability when subjected to in-plane shear loading.

The dynamic properties of honeycomb sandwich can also be influenced by the cell size of a honeycomb core. For an instance, Havaldar et al. (2012) have studied the effect of different cell sizes of PPHC core on the fundamental natural frequency of FRP honeycomb sandwich panels under two different boundary conditions and found that the natural frequencies decreased with increase in cell sizes in both the boundary conditions. The debonding length of the sandwich composites also play vital role on their dynamic properties. For example, Idriss et al. (2013) have stated that the damping effect and stiffness of the sandwich composites were sensitive to the debonding length under static and dynamic loadings.

Most importantly, there are hardly limited research reports available for the dynamic analysis (with both the frequency and damping values) of the PPHC sandwich, despite the fact that it possesses remarkable mechanical properties. Hence, this study focuses on the prediction of the dynamic characteristics of PPHC sandwich composites, theoretically and experimentally and the results have been compared. The paper has exceptionally studied the effect of the different orientations of FRP skins and the different thicknesses of the skin and core on the transverse shear damping of the sandwich with the help of appropriate equations.

2. Constituent materials and their properties

The matrix material consists of the low temperature curing epoxy resin with a specific gravity of 1.14 at 25 °C, the solvent based high temperature curing hardener and the accelerator. The unidirectional glass fiber having a density of 2.50 g/cm^3 was used as the reinforcement. The polypropylene honeycomb core, possessing high strength-to-weight ratio, energy and sound absorption, and corrosion resistance, was supplied by M/s Good fellow Cambridge Limited of London. It is covered with polyester scrim on both sides, which facilitates a better bonding of the honeycomb with the surface panels. It also acts as a barrier to prevent the resin from leaking into the core cell.

The transverse shear moduli and compression modulus of the core in the out of plane direction have been computed by the following Eqs. (1)–(3), developed by Meraghni et al. (1999).

$$G_{xz_{hc}} = \frac{t_w G(1 + 2\cos\theta)}{2k\sin\theta(\cos\theta + 1)}, \tag{1}$$

$$G_{yz_{hc}} = \frac{t_w G(t_w + 2k\sin\theta)}{2k(1 + \cos\theta)(t_w + k\sin\theta)}, \tag{2}$$

$$E_{hc} = \frac{t_w E(1 + 2\cos\theta)}{2k\sin\theta(\cos\theta + 1)}, \tag{3}$$

where $k = (d/2)/\sin\theta$, $\theta = 2\pi/6 = 60°$, k is the hexagonal cell parameter, θ is the cell angle, t_w is the wall thickness with the size of 0.25 mm, d is the diameter of the cell with the size of 8 mm. G and E are the shear and Young's modulus of PP solid materials having the values of 320 MPa and 900 MPa respectively. All these parameters are clearly shown in Fig. 1.