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Characterization of sandwich beams with debonding by linear and nonlinear vibration method

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ABSTRACT

The nonlinear vibration method is used to characterize the behavior of sandwich beams with debonding. The technique focuses on the response of the material's resonance modes as a function of the driving amplitude by sweeping the frequency at various drive levels. Sandwich material used in this study is constructed with glass fibre laminates as skins and with PVC closed-cell foams as core. For an undamaged specimen, the resonance frequency does not change with increased excitation amplitude. For a damaged specimen, the resonance frequency decreases and the inverse quality factor (loss factor) increases proportional with the increasing excitation amplitude. The nonlinear parameters corresponding to the elastic modulus and damping were determined for each frequency mode and each debonding length. The results showed that nonlinear parameters were much more sensitive to damage than linear parameters.

1. Introduction

In the last years the use of sandwich materials is increasing in application industry. The sandwich materials have an interest in applications that require strength, stiffness and lightweight, like aerospace, transport industry, etc. The sandwich is the combination of the two materials called skin and core. The skin material is very stronger and thinner than the core material. They are bonded together with the adhesive joints.

During the use of the sandwich material, he can damage in several ways. The principal modes of damage of composites with foam cores are: fracture of skin, indentation, face wrinkling, debonding between skin and core, failure of the core. In flexural mode the debonding between the skin and the core is one of modes of damage observed by many researchers. The debonding can also occur from several causes: imperfections in the manufacturing process, the degassing of the core foam under direct sunlight, the ability water absorption of cellular cores [1–6], etc. The presence of debonding affects the local and global behavior in static and dynamic sandwich material.

Zenkert [7] showed in his previous paper that debonding in the mid plane of the core drastically reduces the strength of foam core sandwich beams. Shear cracks in the core of sandwich panels may be found as a result of overloading, impact or fatigue. The objective of their studies was to simulate fatigue cracks, to calculate the shear strength in presence of these cracks using finite element method and to verify the calculated strengths with experimental data. Thomson et al. [8] investigated the effects of interfacial crack size and impact damage size on the shear properties failure mechanisms of a sandwich composite. The four-point bending test was used. They showed that the strength was only degraded when the interfacial crack or impact damage exceeded a critical size. Efstathios et al. [9] analyzed the behavior of sandwich with crack under flexural loading by the finite element method. They used different mesh for the crack and core. The authors concluded that the core is subjected to shear. Idriss et al. [10] investigated the effects of debonding length on the fatigue behavior of sandwich composite. The stiffness, hysteresis loop and loss factor were determined for different debonding length and number of cycles. They concluded that parameters (stiffness, hysteresis loop and loss factor) are sensible to debonding length.

Okutan et al. [11] studied the vibration behavior of flat and curved sandwich with different position of debonding. The authors showed that the debonding causes the decrease of frequency and the curvature angle of sandwich is sensible at the frequency response. Kim and Hwang [12] used analytical and experimental analysis to study the effect of the debonding extent on reduction in the flexural bending stiffness and on the natural frequency for honeycomb sandwich beams. In analytical analysis the free vibration of the delaminated sandwich beams is studied using the split sandwich beam model, and the equations of motion are set up for the undelaminated region of the sandwich beam and

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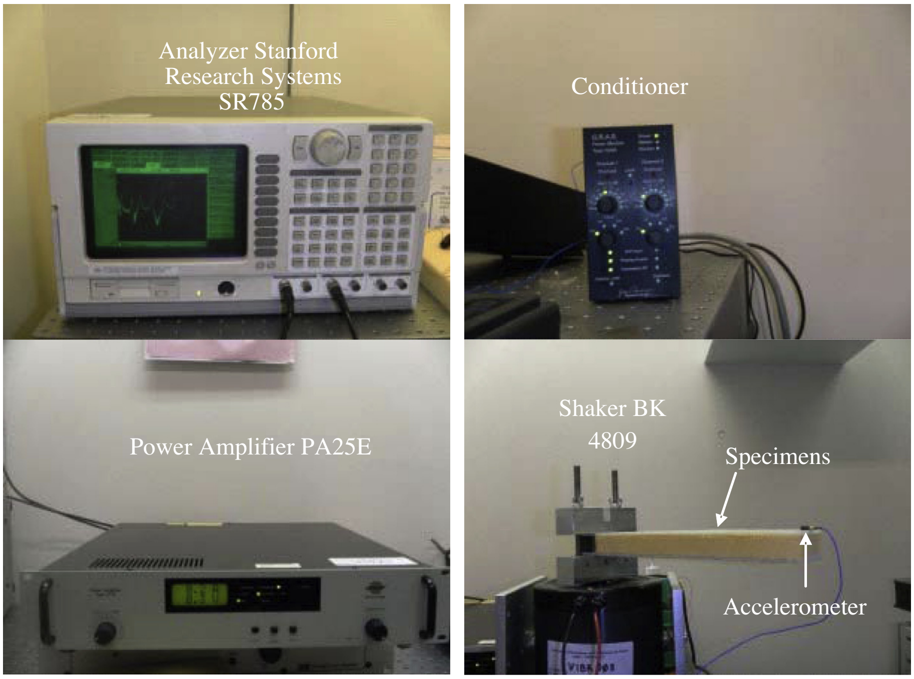

Fig. 1. Experimental setup.

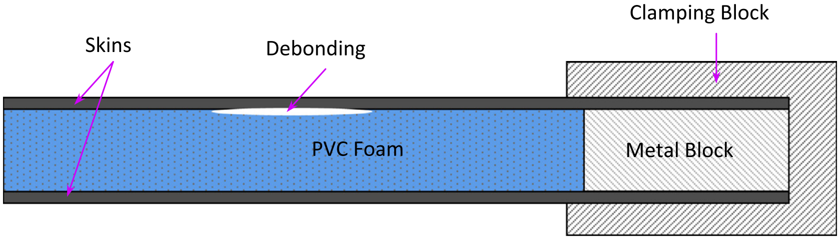

Fig. 2. Sandwich beam with debonding.

the delaminated region of the laminated beams. The frequencies obtained analytically and experimentally show a good agreement. They also showed that the flexural bending stiffness degrades as the extent of the debonding increases in the sandwich beams. Saravanos and Hopkins [13] developed an analytical solution for predicting natural frequencies, mode shapes and modal damping of a delaminated composite beam. This model is based on a general laminate theory which involves kinematic assumptions representing the discontinuities in the in-plane and through-the-thickness displacements across each delamination crack. Many researchers [14-16] were studied the effects of delamination on the frequencies of composite.

The purpose of the present article is to characterize the mechanical behavior of sandwich beams with debonding by linear and nonlinear vibration method. The damage in sandwich beam is characterized by the interfacial debonding progression between the skin and core. The effects of debonding variable length on the frequency shift, inverse quality factors (loss factor) shift and nonlinear parameters were studied for each frequency mode.

2. Theoretical background

The linear elasticity says that the strain (deformation) of an elastic material is proportional to the stress applied to it. The relation stress and strain are linearly related by a constant elastic modulus. Many experiences of static and dynamic showed that the classical theory of elasticity cannot be used to the damaged materials. The damaged materials become highly nonlinear in their stress–strain relation [17–19]. There are two differents nonlinearity behavior: the “classical nonlinearity” and the “non-classical nonlinearity” or hysteretic. Landau theory [20] allows describing the classical nonlinearity behavior of materials. This nonlinearity behavior arises from atomic scale. Classical nonlinear models cannot explain the nonlinear behavior generated by local nonlinear forces due to damage presence. A new theoretical description of nonlinear behavior can be found in [19,20], where terms that describe classical nonlinearity, as well as non-classical nonlinearity, are included. In this case, the constitutive relation between the stress σ and the strain ε can be expressed as follows [21]:

$$\begin{aligned}&\sigma = K(\varepsilon,\dot{\varepsilon}).\varepsilon,\\&K(\varepsilon,\dot{\varepsilon}) = K_0(1+\beta\varepsilon+\delta\varepsilon^2+\alpha F(\varepsilon, sign(\dot{\varepsilon}))),\end{aligned} \tag{1}$$

where σ is the stress, ε is the strain, K_0 is the linear modulus, β and δ represent the classical quadratic and cubic nonlinear parameters, respectively, $\dot{\varepsilon}(t)$ is strain rate, $sign(\dot{\varepsilon}) = 1$ if $\dot{\varepsilon} > 0$ and $sign(\dot{\varepsilon}) = -1$ if $\dot{\varepsilon} < 0$, α is the nonlinear hysteretic parameter. F is a function describing the hysteretic relation between σ and ε. A phenomenological description of the non linear non classical hysteretic elastic modulus based on the Preisach–Mayergoyz space representation [22].