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Nonlinear dynamic behavior of viscoelastic sandwich composite plates under non-uniform blast load: Theory and experiment

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ABSTRACT

In this paper, the dynamic behavior of a viscoelastic sandwich composite plate subjected to the non-uniform blast load is investigated. The theoretical and experimental study is carried out. The plate examined has carbon/epoxy face sheets and an aramid honeycomb core. In the theoretical study, the sandwich plate is modeled using first order shear deformation theory. Because of the large deformations which occurred after the blast load in some tests, geometrical nonlinearities are considered in the derivations. The shear and large deflection effects are considered. The equations of motion are derived by the use of virtual work principle for the sandwich plate. The clamped boundary conditions are considered for all edges of the plate. The viscoelastic properties of carbon/epoxy coupons and sandwich coupons are determined using Dynamic Mechanical Analyzer. The viscoelastic behavior is modeled by using the Kelvin-Voigt linear viscoelastic theory. The equations of motion are obtained in the time domain using Galerkin's method. The nonlinear coupled equation system is solved by Mathematica Software. A special experimental setup is used to obtain the blast pressure for the blast test. The experimental, theoretical and finite element analysis results are compared and the vibration characteristics, peak points, vibration frequencies are found to be in an agreement.

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1. Introduction

Sandwich plates with honeycomb core have been used extensively both in civil and military aircraft industry. Use of sandwich materials in the military structures is growing rapidly. One of the most important features for the modern armies of today is the capability of relocating troops quickly. It is only possible by the use of air vehicles for the transportation of troops and weapons. Therefore, the sandwich armors for the military structures gain importance, since the metallic armors are considerably heavy.

The advantages of sandwich constructions can be summarized as: high stiffness/weight and strength/weight ratios, smooth outer surface, high structural stability, high load bearing capability, long durability, better crack growth and fracture toughness characteristics than the laminated composites, good thermal and acoustic insulation, high strength against high bi-axial compression.

The sources of the blast load are the turbulences, nuclear explosions, sonic booms, shock waves, fuel explosions etc. Aircraft structures can be exposed to the time dependent external loads due to nearby explosions, and strong shock waves at flights in the transonic speeds. Recently, the research activities about the deformation of the structures under the blast load show a great increase. The mechanics of the shock wave spread from the explosion and deformation mechanics of the structure can be investigated in order to comprehend the effect of the explosion. The most important goals for the structures subjected to blast load are decrease of the peak amplitude of transient vibrations, rapid damping of the vibrations and keeping the structural integrity.

Literature review has been conducted for several sandwich constructions [2–4]. A few studies on the nonlinear response of laminated sandwich composite plates which are subjected to blast load have been performed. Dynamic responses of sandwich flat panels to time dependent loads are considered by Librescu et al. [5]. Hause and Librescu [6] investigated the response of anisotropic sandwich flat panels to explosive pressure pulses. Librescu et al. [7] considered linear and nonlinear dynamic response of sandwich panels under blast load. Langdon et al. [8] investigated the air-blast response of sandwich panels with composite face sheets and polymer foam cores. Langdon et al. [9–11] examined behavior of fiber-metal laminates subjected to distributed and localized blast load. Larcher et al. [12] studied on laminated glass subjected to blast load. They described the blast pressure in terms of the

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Friedlander exponential decay equation. Aksoylar et al. [13] considered nonlinear transient behavior of fiber-metal laminated composite plates under blast loads. Karagiozova et al. [14] studied on the response of fiber–metal laminates to localized blast load. Türkmen and Mecitoğlu [15,16] have studied on dynamic response of laminated composite plate under blast load both numerically and experimentally. Kazancı and Mecitoğlu have examined nonlinear dynamic behavior of laminated composite plates subjected to blast load [17]. Nonlinear dynamic response of a sandwich plate subjected to blast load is investigated by Baş et al. [18].

Although there are numerous studies considering the blast load effects on the sandwich composite plates with various core configurations in the open literature, it is not found any study examining the effects of a viscoelastic core on the dynamic behavior of sandwich plates under the blast load. Furthermore, experimental work related to the subject is not found in literature. Esmailzadeh and Jalali [19] studied nonlinear oscillations of viscoelastic simply supported rectangular plates by assuming the Kelvin-Voigt constitutive model. Yan Wei et al. [20] investigated three dimensional solution of a laminated orthotropic rectangular plate with viscoelastic interfaces, described by the Kelvin-Voigt model. Mesquita and Coda [21] considered an alternative Kelvin Viscoelastic formulation for the finite element method. Lekszycki et al. [22] characterized the constitutive parameters of Voigt model and described viscoelastic materials applied in sandwich beams.

In this paper, the dynamic behavior of sandwich composite plates with viscoelastic core subjected to the blast load is investigated. There are some studies on the dynamic behavior of sandwich plates under the uniform blast load in the literature. On the other hand, there is no study in the open literature on the dynamic behavior of sandwich plates with viscoelastic core under the non-uniform blast load. A non-uniform pressure function is constructed and fitted to the experimental results to accurately describe the blast pressure.

The equations of motion of sandwich plates with laminated composite faces and viscoelastic core are obtained using Hamilton's principle. The geometric nonlinearities are taken into account by von Kármán large deflection theory of plates. The shear effects are considered by the first order shear deformation theory. The viscoelasticity is modeled using Kelvin-Voigt's linear viscoelastic theory. The Kelvin-Voigt model is preferred since it has a very simple stress-strain relationship. Kelvin-Voigt model can also describe the creep, elastic recovery and viscous recovery phenomena quite successfully. The Galerkin method is adapted to the equations of motion by choosing the trial functions for the displacement field and the coupled equations are obtained in the time domain. The resulting equations are solved using Mathematica software. The viscoelastic dynamic behavior of sandwich plates is also investigated by using ANSYS finite element software. SHELL 281 element of ANSYS element library is used to discretize the solution domain and the Newmark time integration scheme is applied to obtain transient solutions. The Rayleigh damping is adopted to model the viscoelastic behavior of the sandwich plate.

In the experimental side of the study, the rectangular sandwich plates with laminated composite faces and honeycomb core are produced by wet hand lay-up technique. The composite sandwich plate is cured in a heated vacuum table. The blast pressure is obtained by the use of a shock tube which its open end is closed with a membrane tearing at a level of internal pressure. The plates are clamped at all edges and mounted in front of the shock tube. The variation of blast pressure with time is measured by using two miniature pressure transducers placed at the midpoint and near the edge of the plate front face. The strain rosette which is placed at the midpoint of plate back face is used to obtain the strain time histories. The strain data are acquired by EX1629 48-Channel VXI Technology trademarked Straingage Instrument. On the other hand, the viscoelastic properties of materials used for the production of sandwich plates are determined using Perkin Elmer branded Diamond Dynamic Mechanical Analyzer (DMA). The damping properties are used in the theoretical-approximate solution.

The theoretical and experimental results are compared. The vibration characteristics, peak points, vibration frequencies are found to be in an agreement. The effects of face layer number and core thickness on the dynamic behavior are investigated. The effects of eccentricity of the non-uniform blast pressure are also examined to understand how it changes the dynamic behavior.

2. Experimental study

In the experimental study, the rectangular sandwich plates with laminated composite faces and viscoelastic core are produced in the Composite Structures Laboratory in Istanbul Technical University. Polypropylene and aramid honeycombs are used as core materials.

Core materials can be seen in Fig. 1. Aramid honeycomb material has 4.0 mm cell size and 1.5 mm thickness. PP honeycomb material has 8.0 mm cell size and 10 mm thickness.

Composite sandwich plates are produced by using wet lay-up with vacuum bagging technique and cured in the HCS7500-06-321212 Heated Vacuum Curing Table acquired from Heatcon Composite Systems Company. Curing table has the capability of setting curing time and temperature during ramp. As epoxy resin, HEXION Specialty Chemicals trademarked MGS L285 adhesive and MGS L287 hardener are used. During the production, 0° orientation is used for surface material carbon plies and plates awaited 8–10 h under the pressure of 750 mbar.

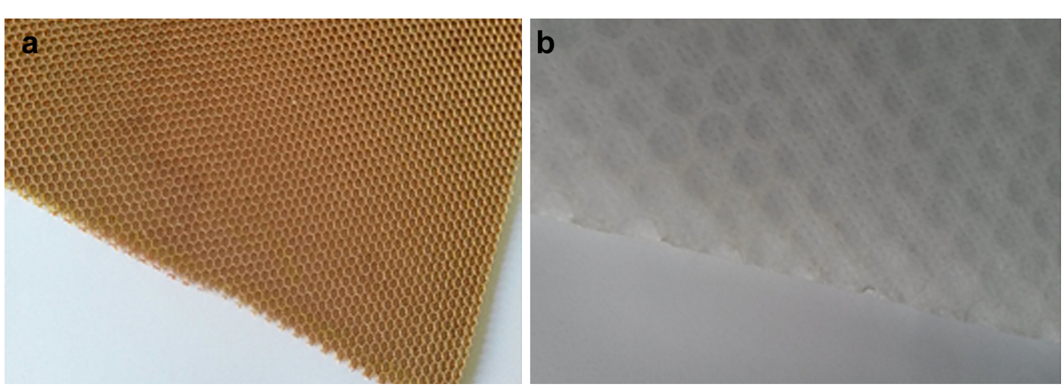

Fig. 1. Core materials (a) aramid honeycomb (b) polypropylene honeycomb.

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