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Curved sandwich composites with layer-wise graded cores under impact loads

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ABSTRACT

Sandwich composites with single type foam are very much prevalent in the applications to absorb energy under impact load. However, there is increasing awareness that graded cores in sandwich composites can significantly affect the impact performance. In this work, the perforation energy and failure modes of curved sandwich composites with layer wise graded cores are studied experimentally. Three types of foam were used for flat and curved sandwich composites with layered cores. A series of six different core layer arrangements were studied. The contact forces, displacements and corresponding perforation energies of square panels were measured and failure modes after perforation were observed. The results indicate that the perforation energies of the sandwich panels are dependent on various geometrical and material parameters. The perforation energies of the curved panels with single type foam were increased compared to similar flat panels, whereas panels with graded foam behaved differently due to the foam layer arrangements. Furthermore, it was observed that the failure modes were not similar when the panels were perforated. Contribution of present study to current literature is the use of different core layer arrangements to increase the impact performance of curved sandwich panels which are inevitable parts of various applications.

1. Introduction

Performance demands for engineering applications are increasing and necessitate looking for new materials. Sandwich composites as a special class of composite materials are being used increasingly in various engineering applications such as aeronautic, astronautics, naval/marine and automotive industries because of their excellent properties of high stiffness-to-weight ratios, strength-to-weight ratios and energy absorption capabilities [1]. Despite of all of their advantages over traditional materials, impact damage of sandwich structures is one of the major concerns which affect strength and reliability of the structure. The core materials play a crucial role in the impact response of sandwich structures. Common cores used are foam, honeycomb, corrugated or truss structures. In recent years, piece-wise, layer-wise and exponentially functionally-graded cores are utilized as core materials in sandwich composites. Functionally Graded Material (FGM) belongs to a class of advanced materials in which the material properties are varied gradually or layer by layer as the dimension varies. They eliminate the sharp interfaces existing in composite materials where failure is likely to be initiated. These sharp interfaces are replaced with gradient interfaces which produce smooth transition from one material to the next [2–4]. Due to their unique characteristics, FGMs are widely used in many specific applications. However, owing to the complexity of these structures and their failure characteristics, a lot of problems waiting to be solved are available on static loading, impact loading, vibration and stability of functionally graded composites.

Bhangale and Ganesan [5] investigated buckling and vibration behavior of a functionally graded sandwich beam having a constrained viscoelastic layer. In their numerical studies, the effect of power law index and core to stiff layer ratio on the thermal buckling temperature, as well as on vibration are examined. Rahmani et al. [6] carried out the vibration analysis of sandwich beams with a flexible functionally graded syntactic foam as the core material. They noticed that the modes of the beam with FG core were of the mixed nature relative to those of the beam with conventional core. Avila [7] and Apetre et al. [8] focused on failure modes of layered foam-based sandwich structures under static and impact loading, respectively. Apetre et al. showed that functionally graded cores can be used effectively to mitigate or completely prevent impact damage in sandwich composites while Avila determined that the best beam configuration where the core layer with highest density was located below the upper face-sheet. Zhou et al. [9] investigated the influence of core properties and configurations

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on the perforation resistance of the sandwich structures based on cores fabricated by bonding three foam layers with different densities together. Their results showed that placing the high density foam core against the top surface skin can lead to an improved perforation resistance relative to sandwich panels in which the higher density foam is in contact with the distal surface. Some studies are also available on response of sandwich composites with graded core under shock wave loading [10,11] and fatigue loading condition [12]. Gardner et al. [10] analyzed the shock pressure profiles and real time deflection images of sandwich composites with increasing number of monotonically graded foam core layers. Their results indicated that increase in foam core layers reduce the acoustic wave impedance mismatch between successive layers. Wang et al. [11] studied a three-layer simply-supported sandwich beam with stepwise graded core materials and subjected it to transverse blast loading to analyze the effect of the layer sequence at midpoint deflections. They concluded that monotonically increasing the wave impedance of the core layers enhanced the blast resistance of the sandwich structures. From the literature survey on sandwich composites it is visible that the behaviors of sandwich composites under impact loading mainly focus on flat ones. Impact response of curved sandwich composites with graded/layered foam core has not been investigated whereas; curvature plays an important role in the deformation characteristics of structures. In recent years, studies on curved FGM structures subjected to pure bending are reported by Birsan et al. [13] and Nie and Zhong [14]. They determined the effective stiffness properties and elasto-plastic stress distribution of various functionally graded curved beams in order to characterize their mechanical behavior.

The objective of this study is to provide experimental data for determining the impact perforation resistance of curved sandwich panels with E glass/epoxy skins and PVC foams of various properties. The proposed studies will help to assess the effects of different core layer arrangements and curvature on the impact energy level to cause perforation and failure characteristics of sandwich structures with layer-wise graded cores and to determine the better core design of such composites. Knowledge of interaction between perforation energy and failure modes will serve the needs of structural designers. In addition, the present work will be used to provide a comparison for numerical investigations about sandwich composites with layer-wise graded cores.

2. Experimental work

2.1. Materials, manufacturing and test specimens

The sandwich composites utilized in this study consist of E-glass/epoxy as skin and PVC foam as core. Areal density of fibers used as skins is about 300 g/m^2. Stacking sequence of E-glass fibers placed in skins is $[0°/90°/+45°/-45°]_s$. Table 1 shows the material properties of unidirectional E-glass/epoxy used for manufacturing of sandwich composites. The core materials used in the present study are series of AIREX® C70 which are closed-cell and cross-linked rigid foams. The three types of AIREX® C70 series foam (C70.55, C70.90 and C70.200) were selected for the study. Material properties of three foams from the manufacturer's data are given in Table 2.

Fig. 1 schematically illustrates the flat and curved sandwich panels manufactured from E-glass epoxy sheets and three types of PVC foam core. The skins have a thickness (t_s) of 0.75 mm each, while the thickness of each foam layer ($t_{f1} = t_{f2} = t_{f3}$) is 5 mm. The final sandwich panels are square plates (L × W) of 100 × 100 mm dimensions with a total thickness of 16.5 mm. The curved sandwich panels were formed having two different radii of curvature (r = 100 and 160 mm). Table 3 summarizes all configurations investigated in the present study. First three configurations with single core layers were manufactured for comparison with graded composites. As can be seen from the table; all sandwich specimens with graded foam have identical foam layer material, number and thickness but different core layer arrangement and curvature. The number written after R in specimen codes denotes the radius of the panel curvature.

Curved foam layers required for this study were prepared by thermoforming process as described at AIREX® Processing Guidelines. Two different curvatures of panels were provided by using special molds having the same curvature of panels. Flat foam sheets placed in curved mold were first put in a heated oven. They were kept in the oven for 45 min at a temperature of 130 °C, which was determined according to the type and thickness of the foams. Pressure was applied by means of weights. Three 5 mm thick foam layers with different mechanical properties were bonded to each other using Biresin CR80 epoxy resin with Biresin CH80-2 hardener. Both skins were then co-cured to the layered foam cores by means of vacuum infusion process for manufacturing of the sandwich composites with six types of layered foam core arrangements. The resin system for the production of the specimens was Hunstman Araldite LY 564 with Huntsman Aradur 3487 hardener. The weight mixing ratio of resin and hardener is 100:34. Cure and post-cure of the specimens were carried out according to manufacturer specifications at room temperature for more than 24 h and at 80 °C for 15 h, respectively. All sandwich panels used in experiments are presented in Fig. 2.

2.2. Impact tests

Impact testing of the panels was carried out using CEAST-Fractovis Plus Impact Testing Machine instrumented impact drop tower with a pneumatic rebound brake system and impulse data

Table 1
Mechanical properties of unidirectional E-glass/epoxy used in present study.

Longitudinal elastic modulus (GPa)	Transverse elastic modulus (GPa)	Poisson's ratio	Shear modulus (GPa)	Longitudinal tensile strength (MPa)	Transverse tensile strength (MPa)	Longitudinal compression strength (MPa)	Transverse compression strength (MPa)	Shear strength (MPa)
31	12	0.3	3.20	706	122.5	472	183	77

Table 2
Mechanical properties of Airex C70 series foam cores used in present study.

Core	Density (kg/m^3)	Compressive strength (MPa)	Compressive modulus (MPa)	Tensile strength in the plane (MPa)	Tensile modulus in the plane (MPa)	Shear strength (MPa)	Shear modulus (MPa)	Shear elongation at break (%)
C70.55	60	0.90	69	1.3	45	0.85	22	16
C70.90	100	2.0	130	2.7	84	1.7	40	23
C70.200	200	5.2	280	6.0	175	3.5	75	30