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ScienceDirect
Composite Structures 83 (2008) 335–340
COMPOSITE STRUCTURES
www.elsevier.com/locate/compstruct

A new hybrid concept for sandwich structures

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Available online 17 May 2007

Abstract

Sandwich structures are considered as optimal designs for carrying bending loads and can be either metal (aluminium faces and honeycomb or metal foam cores) or polymer structures (composite faces with polymer foam cores). In this paper, a new hybrid sandwich structure has been developed by combining most of the advantages of metallic and polymeric materials while avoiding some of their main disadvantages. For this new concept metal sheets are used at the outer surfaces to maximize rigidity while introducing in between lightweight cores adhesively bonded to keep the whole structure together. Furthermore, composite or wood layers may be used as intermediate layers to improve impact resistance. Potential methods for the manufacturing of this new structure are based on compression under vacuum. The results include the study of several panel configurations theoretically based on Finite element analysis and on the modified simplified equations and experimental results in the most representative cases of the study.
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Keywords: Sandwich structure; Finite element analysis; Three-point bending; Metal skins; Foam core

1. Introduction

Although sandwich structures are considered as optimal set-ups for carrying bending loads, their structural design and manufacturing entail knowledge and experience [1]. Many researchers have studied the variety of the failure mechanisms of the sandwich structures either under static loads, e.g. [1,3,6,7], or under dynamic loads, e.g. impact [7,8], where the importance of the materials' choice is prevailing.

In order to tackle some of the weaknesses of the existing materials for sandwich structures some researchers have studied successfully certain material combinations either in the core [8–10] or introducing internal layers [11] or even by mixing of completely different materials such as metals and polymers with applications that may be found in the building sector [12] (wall and roof panels) and in the automotive sector (thin steel or aluminium face sheets and polymer cores) [13]. These hybrid sandwich structures although improving considerably the structural performance of either of their materials can not be used as primary structures.

In this paper, a new hybrid sandwich structure has been developed by combining most of the advantages of metallic and polymeric materials while avoiding some of their major disadvantages. The design concept is to use metals at the face sheets in order to maximize rigidity and extremely lightweight cores while introducing an intermediate layer from composite materials or wood between the face sheets and the core appropriately bonded to keep the whole structure together [14,15].

The rest of the paper is organised as follows: in Section 2 the classic sandwich theory is analysed and in Section 3 the new hybrid sandwich concept is analysed while in Section 4 other structural issues such as impact behaviour are addressed. In Section 5 theoretical and experimental results are presented for the proof of concept and in Section 6 conclusions are drawn.

2. Classic sandwich theory

In general, to study and optimise a structure its basic features need to be modelled and analysed. For this reason,

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0263-8223/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compstruct.2007.05.002

a narrower version of a panel (Fig. 1a) with equivalent loads and conditions will be studied extensively in theoretical simulations and experimental tests.

Considering the basic beam theory in a typical three-point bending situation the mid-point deflection is given as

$$\delta = \frac{PL^3}{48(EI)_{\mathrm{eq}}} + \frac{PL}{4(AG)_{\mathrm{eq}}} \tag{1}$$

where P is the load, L and b are the beam's span and width, E and G are the materials' Young's and shear modulus. In the conventional sandwich structure there are two materials composing the structure: the faces and the core so the contribution of each material can be analysed straightforward. As in the present case we will study sandwich structures with

(a) face thickness considerably smaller than the core thickness ($t_f \ll t_c$)
(b) core stiffness significantly smaller than the faces stiffness ($E_f \gg E_c$)
(c) length considerably larger than thickness ($L \gg t_c$)

the mid-point deflection for long beams in three-point bending (Eq. (1)) becomes:

$$\delta = \frac{PL^3}{24E_f t_f t_c^2 b} \tag{2}$$

The failure of a sandwich structure is a very complicated phenomenon and may be due to various failure mechanisms in one of the materials that composes the structure. These mechanisms have been analysed and tested by various researchers [1,2,12] and the allowable mid-point loadings in a three-point test with respect to each failure mode can be summarised as [2]:

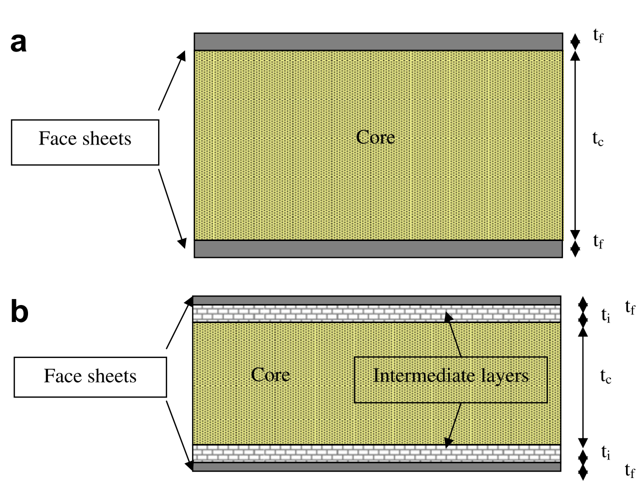

Fig. 1. Sandwich structure section showing the thin outer faces (top and bottom) and the inner thick core. (a) Classic concept. (b) Hybrid concept showing also the intermediate layers.

$$\text{Face microbuckling (FMB)}: \quad \frac{P}{b} = \frac{4t_f t_c \sigma_f}{L} \tag{3}$$

$$\text{Face wrinkling (FW)}: \quad \frac{P}{b} = \frac{2t_f t_c}{L}\sqrt[3]{E_f E_c G_c} \tag{4}$$

$$\text{Core shear (CS)}: \quad \frac{P}{b} = 2t_c \tau_c \tag{5}$$

$$\text{Indentation(Ind)}: \quad \frac{P}{b} = \sqrt[3]{\frac{\pi^2 E_f \sigma_c^2 t_f^3 t_c}{L}} \text{or} \frac{P}{b} = \sqrt{\frac{16E_f E_c t_f^3 t_c}{3L^2}} \tag{6}$$

where $b, L, t_f, t_c, P, E_f, E_c, G_c, \sigma_f, \sigma_c, \tau_c$ are, respectively, the width and length of the beam, the face sheets' and core's thicknesses, the maximum point load the Young's modulus for the skins and the core, the core shear modulus, the maximum stress for the face sheets and the maximum compression and shear stresses for the core.

Eqs. (3)–(6) give a rough idea of how each material contributes to the failure of the whole structure. For example if a low cost foam core is used it is very likely that the beams will fail either due to core shear or due to indentation especially in three-point loading.

However, this theoretical analysis does not consider three basic issues: the interaction between failure mechanisms, the role of the adhesion between the materials and the contribution of a third material, between the face sheet and the core. The first two issues are very complicated and need separate studies but at the present paper the role of the third intermediate material will be addressed.

3. The hybrid sandwich concept

The classic sandwich structure consists of two thin and stiff face sheets and a thick, lightweight and stiff enough material in between. Although this structure seems optimal in practice the large differences between the structural properties of the materials in contact create many problems. Moreover the cost of the existing core materials is very high pushing towards the selection of the lowest possible performance cores. Of course the final selection of the core material is a compromise between these limits, the cost, the weigh but also other characteristics of the core such as the impact resistance, fatigue, moisture, etc. Because the homogeneity of the core materials makes this compromise very tough, some attempts to develop either graded cores or two stacked foam cores [4,9–11] have been presented.

A compromise between the homogeneous and graded cores is the introduction of an intermediate layer as can be seen in Fig. 1b. This layer of thickness t_i should be much stiffer than the core material, lightweight enough and preferably much thicker than the face sheet. This intermediate layer will allow the use of very thin face sheets, e.g. metals, and very cheap cores, e.g. XPS or PUR, at the expense of a slightly higher weight. Furthermore, if a common material is chosen, e.g. wood, this intermediate layer will also decrease the cost considerably. However, a very good adhesion between all these three materials has to be ensured.

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