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A solution including skin effect for stiffness and stress field of sandwich honeycomb core

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Abstract

Honeycomb sandwich panels have been increasingly used in every possible field, and their efficient load carrying capacity attributes have attracted considerable attention. All previous studies have been focused mainly on stiffness, neglecting for the most part skin effects. This paper represents an important further contribution by developing an analytical model that permits the computation of stiffnesses as well as interfacial stresses considering the skin-effect for hexagonal honeycomb sandwich, subjected to in-plane and out-of-plane forces. An explicit analytical model is derived based on equilibrium equations, where boundary conditions imposed by the skin effect are appropriately considered. The accuracy of the solution is verified through close correlations with existing stiffness formulations and finite element results. The skin effect on both stiffness and interfacial stress distribution is analytically defined. The present model is then used to carry out a parametric study on interfacial stresses, and to detect the critical sections in the structure where further consideration should be given for design purposes. The method provided in this study can be used for accurate analysis and design of sandwich structures.

Keywords: Sandwich honeycomb panel; Skin effect; Stress distribution; Explicit solution; Finite element analysis; Parametric study

1. Introduction

A typical sandwich panel is made of two stiff skins, separated by a lightweight honeycomb core. It may be designed so that each component is utilized to its ultimate limit. This feature makes sandwich structures

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attractive in various engineering fields where stiffness and strength must be met with minimum weight (Vinson, 1999). The concept of sandwich construction has been traced back to the mid 19th century (Fairbairn, 1849), while the broad introduction of the sandwich concept in aircraft structures started at the beginning of World War II. Nowadays sandwich panels and shells have been widely used in aerospace, shipbuilding, civil infrastructure and other industries (Davalos et al., 2001).

Conventionally hexagonal honeycomb sandwiches (see Fig. 1) have been applied in the aerospace industry since the 1940's, and have been increasingly used in every possible field. The commonly used core materials include aluminum, alloys, titanium, stainless steel, and polymer composites. Apparently, the computational models on honeycomb sandwiches are generally based on the equivalent replacement of each component with homogeneous continuum, due to expensive computation of 3-D detailed properties. Therefore, to accurately represent the equivalent properties has been a perennial challenging topic that attracted a lot of investigations. From Fig. 1, one can intuitively conclude that honeycomb sandwich structures behave like I-beams: the outer facesheets correspond to the flanges, and carry most of the direct compression/tension bending load, and the lightweight core corresponds to the I-beam web. The core supports the skins, increases bending and torsional stiffness, and carries most of the shear load (Noor et al., 1996). This characteristic of a three-layer arrangement leads to classical sandwich theory (Allen, 1969; Zenkert, 1995). Unlike the facesheet, which can even be a laminated plate, the equivalent properties of honeycomb cores are more complicated. A lot of research has been devoted to this area. These include Warren and Kraynik (1987), Gibson and Ashby (1988), Fortes and Ashby (1999), and included in the book of Gibson and Ashby (1988) is the first systematic literature review in the field. All these mathematical models are based on pure cellular structures and the presence of the facesheet is not considered. As a result, the existing analytical solutions do not agree well with experimental results (Shi and Tong, 1995).

In order to more accurately describe the elastic moduli of the core, Penzien and Didriksson (1964) introduced the concept of warping effect, or skin effect, into the model. Later Grediac (1993), Shi and Tong (1995), Becker (1998), and Xu and Qiao (2002) further considered this effect in their studies. It is interesting to point out that different researchers defined this effect in different ways, such as warping constraint by Penzien and Didriksson (1964), thickness effect by Becker (1998), bending effect by Grediac (1993), and skin effect by Xu and Qiao (2002). Recently Chen and Davalos (2004) decomposed this effect into shear and bending warping effects. However, all of these studies, either using 2-D model or finite element (FE) method, were focused on the stiffness study only, and no work is available on the stress distribution at the interface, partly due to the following reasons: (1) the skin effect introduces a complicated stress field

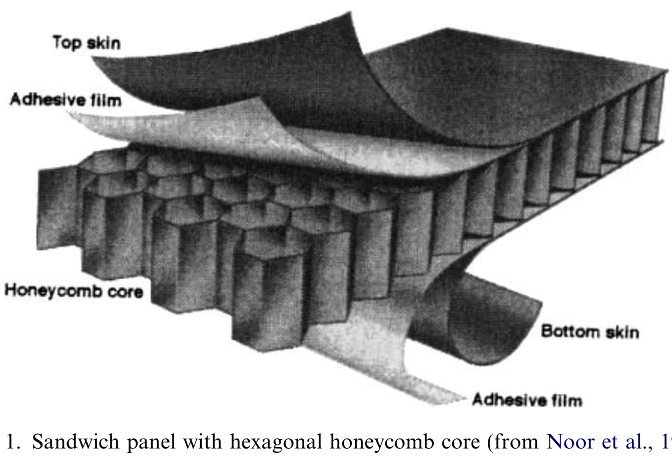

Fig. 1. Sandwich panel with hexagonal honeycomb core (from Noor et al., 1996).