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Elastic foundation analysis of local face buckling in debonded sandwich columns

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Abstract

An elastic foundation model is developed for analysis of the local buckling behavior of foam core sandwich columns containing a through-width face/core debond. Parametric studies are performed to evaluate the effect of debond length, core thickness, core density, face sheet thickness, face sheet modulus, and boundary conditions, on the local buckling load. Model predictions are compared to experimental results obtained for sandwich specimens made from glass/vinyl-ester face sheets over various PVC foam cores containing a face/core debond. The predictions are in reasonable agreement with measured buckling loads.

Keywords: Debonded sandwich; Buckling; Elastic foundation; Parametric analysis

1. Introduction

Sandwich structures are known to be strong, stiff and light (Zenkert, 1997; Vinson, 1999). In an ideal sandwich panel the faces are perfectly bonded to the core. In practice, however, the faces may be locally separated from the core as a result of initial manufacturing flaws. Furthermore, during service, the structure may be subject to impact loading by hard objects, wave slamming or underwater explosions, events that are likely to inflict core crushing and/or local separation of face and core (Shipsha et al., 2003). Debonds may be critical if the structure is loaded in compression, since the debond may buckle and propagate leading to collapse of the structure (Shipsha et al., 2003; Kim et al., 1993). The typical behavior is characterized by local buckling of the separated face sheet region followed by debond propagation in the interfacial region or crack propagation in the core (Shipsha et al., 2003; Vadakke and Carlsson, 2004). Consequently, in most cases, the analysis of debond growth requires consideration of two major phenomena, first the local buckling of the

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debonded face sheet, and then the growth of the post-buckled debond (Chai et al., 1981; Whitcomb, 1981). The post-buckling problem is inherently non-linear because of the large deformations of the buckled region. Following the work of Chai et al. (1981) and Whitcomb (1981), numerous studies have been conducted on the related problem of delamination buckling induced by in-plane compression loading of laminated composite structures. Of those studies, the work of Vizzini and Lagace (1987) is of special interest to our study. Vizzini and Lagace addressed the problem of delaminations in composite laminates at the ply level, assuming the delamination as partially supported by regions of interply matrix of thickness of the order of a fiber diameter, which was considered as an elastic foundation. They developed a one-dimensional elastic foundation model to evaluate the local buckling load for a composite laminate containing symmetrically located near-surface delaminations. Sleight and Wang (1995) extended the Vizzini and Lagace model to sandwich columns with symmetrically located through-width face/core (F/C) debonds. Symmetrically located F/C debonds, however, are rarely encountered in actual sandwich structures such as boat hulls, where impact loading and wave slamming of the hull tend to occur at one side only.

In this work we develop a numerical approach (elastic foundation) for prediction of the local buckling behavior of sandwich columns with a single F/C debond. The model is an extension of the Vizzini–Lagace and Sleigth–Wang symmetric models to a sandwich column with only one F/C debond. The effects of parameters such as debond length, core density, core thickness and face sheet thickness are studied. Model results are compared to experimentally obtained data.

2. Elastic foundation model

A section of a sandwich column containing a through-width face/core debond, Fig. 1, is analyzed here using an elastic foundation model (EFM). Fig. 2 outlines the EFM of a sandwich section with identical face sheets containing an F/C debond at the upper face–core interface. For the sake of analysis, the structure is divided in two halves, the upper containing the F/C debond (*side 1*), and the lower representing the fully bonded side (*side 2*). Both face sheets are modeled as beams of length L, thickness t_f, width b, and bending stiffness E_fI, where $I = bt_f^3/12$ and E_f is the effective flexural modulus of the laminate as defined in terms of the bending stiffness matrix [D] by Whitney (1987). This effective flexural modulus reduces to the Young's modulus (E) when the faces are isotropic. Each face sheet is subject to a compressive load P. The debond of length a, is located at the upper face/core interface at the center of the section. The core is represented by an elastic foundation with a spring constant (per unit length)

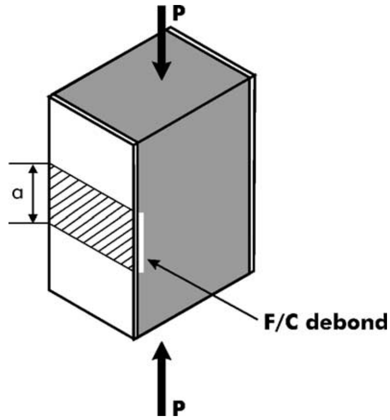

Fig. 1. Sandwich specimen with a through-width face/core debond loaded in compression.

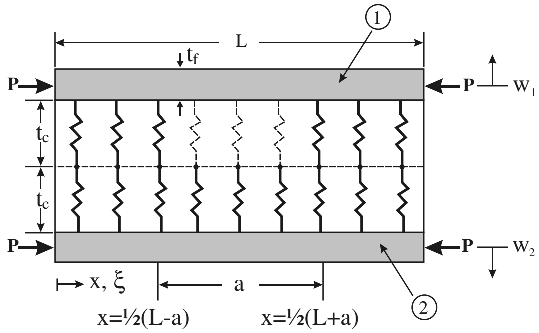

Fig. 2. Schematic representation of the elastic foundation model.