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Journal of the Mechanics and Physics of Solids 54 (2006) 2242–2280

JOURNAL OF THE MECHANICS AND PHYSICS OF SOLIDS

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The impulsive response of sandwich beams: Analytical and numerical investigation of regimes of behaviour

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Received 5 May 2006; accepted 10 July 2006

Abstract

An analytical model is developed to classify the impulsive response of sandwich beams based on the relative time-scales of core compression and the bending/stretching response of the sandwich beam. It is shown that an overlap in time scales leads to a coupled response and to the possibility of an enhanced shock resistance. Four regimes of behaviour are defined: decoupled responses with the sandwich core densifying partially or completely, and coupled responses with partial or full core densification. These regimes are marked on maps with axes chosen from the sandwich beam transverse core strength, the sandwich beam aspect ratio and the level of blast impulse. In addition to predicting the time-scales involved in the response of the sandwich beam, the analytical model is used to estimate the back face deflection, the degree of core compression and the magnitude of the support reactions. The predictions of the analytical model are compared with finite element (FE) simulations of impulsively loaded sandwich beams comprising an anisotropic foam core and elastic, ideally plastic face-sheets. The analytical and numerical predictions are in good agreement up to the end of core compression. However, the analytical model under-predicts the peak back face deflection and over-predicts the support reactions, especially for sandwich beams with high strength cores. The FE calculations are employed to construct design charts to select the optimum transverse core strength that either minimises the back face deflections or support reactions for a given sandwich beam aspect ratio or blast impulse. Typically, the value of the transverse core strength that minimises the back face deflection also minimises the support reactions. However, the optimal core strength depends on the level of blast impulse, with higher strength cores required for greater blasts.

Keywords: Sandwich beams; Blast response; Optimisation; Dynamic plasticity; FE simulations

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doi:10.1016/j.jmps.2006.07.001

1. Introduction

The blast resistance of structures is of current academic and industrial interest, with sandwich structures being proposed as alternatives to conventional monolithic structures in order to enhance blast resistance. The prototypical problem is sketched in Fig. 1: a planar underwater or air blast impinges a clamped sandwich beam. Several recent studies have shown that sandwich structures subjected to blast loading outperform monolithic structures of equal mass, see for example, Fleck and Deshpande (2004) and Xue and Hutchinson (2004). However, the relation between the sandwich core material properties and the sandwich beam performance remains unclear. The aim of this study is to investigate this relationship using analytical and finite element (FE) methods.

Fleck and Deshpande (2004) have developed an analytical model for the shock resistance of clamped sandwich beams by separating the response of these beams into three sequential stages: the fluid–structure interaction stage I up to the point of first cavitation of the fluid, the core compression stage II and finally a combined beam bending and stretching stage III. The model of Fleck and Deshpande (2004) temporally decouples the three stages of the sandwich beam responses and provides a framework for understanding the blast response of sandwich beams. The qualitative predictions of the Fleck and Deshpande (2004) analysis for the front face velocity v_{f} and back face velocity v_{b} are sketched in Fig. 2a and b. The core is taken to be sufficiently strong such that it decelerates the impacted front face and simultaneously accelerates the back face to a common velocity over a time period, which is significantly shorter than that of the subsequent co-operative sandwich beam response. The deflection of the back face during the core compression phase (stage II) is also assumed to be small compared to that during the subsequent sandwich beam response. Core compression is either partial or complete: a blast of sufficiently high intensity will cause the front face to slap against the back face with full densification of the core, see Fig. 2b. A low intensity blast, however, will only partially densify the core at the time when v_{f} drops to the value of v_{b}, see Fig. 2a.

Recent FE simulations by Rabczuk et al. (2004), Liang et al. (2006) and McShane et al. (2006) suggest that the Fleck and Deshpande (2004) model may over-estimate or under-estimate the deflections of the sandwich beams under blast loading. These discrepancies

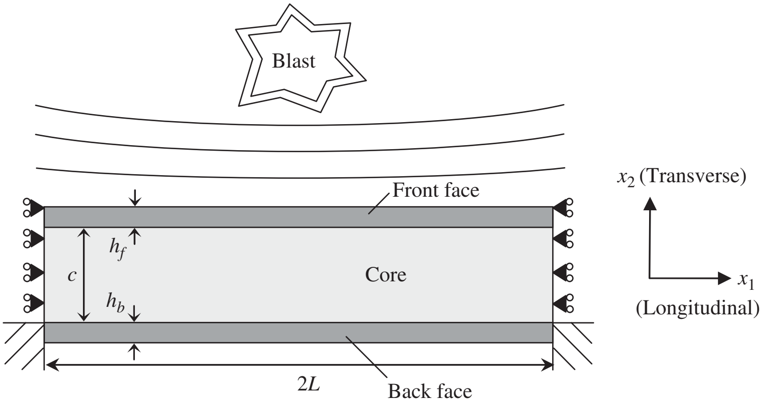

Fig. 1. Geometry of the sandwich beam and schematic of the problem under consideration.