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The dynamic indentation response of sandwich panels with a corrugated or Y-frame core

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ABSTRACT

The dynamic indentation response of stainless steel sandwich panels with a corrugated core or a Y-frame core has been explored using the finite element method to gain insight into the potential of the cores to mitigate against collisions over a wide range of impact velocities pertinent to land and sea-borne vehicles. Back-supported sandwich panels were impacted on the front face by a flat-bottomed or a circular punch at constant velocity ranging from quasi-static loading to 100 m/s. At velocities below 10 m/s the forces on the front and back faces are equal but inertia stabilisation raises the peak load above its quasi-static value. This strength elevation is greater for the corrugated core than for the Y-frame core, and more pronounced for the flat-bottomed punch than for the circular punch. For velocities greater than 10 m/s, the indentation force applied to the front face exceeds the force transmitted to the back face due to plastic-shock effects. In this regime, the force transmitted to the back face by the Y-frame core is markedly less than for the corrugated core, and this brings a performance benefit to the Y-frame, i.e. it protects the underlying structure in the event of a collision.

1. Introduction

More than 200 maritime accidents were recorded in the Gulf of Finland from 1997 to 2006 [1]. About 50% of those accidents were grounding (the impact of a ship on the seabed) and another 20% were ship–ship collisions. The frequency of such accidents has the potential to increase in the future as maritime traffic increases and as vessels become larger and faster. Thus, it is vital that ship structures have adequate strength and energy absorption capacity to resist collisions. The crashworthiness of most tankers relies on a conventional double hull design, with minimal coupling between inner and outer hulls. However, improved crash performance can be obtained by sandwich construction [2]. Similarly, the crashworthiness of land vehicles (and their resistance to security threats such as air blast) can be improved by the appropriate choice of an energy absorbing core in a sandwich configuration. This motivates the present basic study: we explore the resistance of sandwich cores to local indentation, and determine the indentation response as a function of impact velocity. Our intent is not to analyse the precise geometry of a particular vehicle, but to explore the significance of localised impact rather than distributed crushing on a sandwich panel, over a wide range of impact velocities.

A recent example of sandwich construction is the Y-frame hull design developed by Damen Schelde Naval Shipbuilding,[1] see Fig. 1a. Full-scale collision trials have been performed on the Y-frame structure and it has been demonstrated that its crashworthiness exceeds that of a conventional double hull design [3]. These full-scale collision trials also revealed that the Y-frame hull design collapsed by indentation, with the inner hull undergoing negligible plastic deformation. The corrugated core, see Fig. 1b, is a competing design to the Y-frame core. No full-scale collision tests on the corrugated core have been reported in the open literature, but its performances relative to those of the Y-frame core have been investigated in the laboratory, as follows. The quasi-static three-point bending response of sandwich beams with a corrugated core or with a Y-frame core has been studied by Rubino et al. [4] and St-Pierre et al. [5]. Both studies have shown that corrugated and Y-frame sandwich beams of short spans (such as those used in a ship hull) collapse by indentation. These results suggest that additional insight into the deformation of a sandwich panel during a ship collision is gleaned by considering its fundamental indentation response. It is currently unknown whether

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the corrugated and Y-frame sandwich panels have potential to mitigate against collisions in automotive and rail transport. Collisions on land are likely to occur at much higher velocities than on sea; hence, there is a need to quantify the effect of loading velocity on the indentation response of the sandwich panels.

The dynamic compressive response of corrugated and Y-frame cores, subjected to uniform loading at velocities ranging from 1 to 100 m/s, was measured by Tilbrook et al. [6] and investigated numerically by McShane et al. [7] (for the corrugated core only). Both studies identified two regimes of dynamic behaviour differentiated by comparing the forces on the impacted and rear faces. First, at low impact velocities, inertia stabilisation of the core members against buckling increases the collapse load compared to the quasi-static case, but the forces on the impacted and rear faces are equal. Second, at high velocities, the force on the impacted face is higher than that on the rear face due to plastic-shock effects. In the current study, the finite element method is used to determine the relative significance of these two regimes when the loading is localised rather than uniform in nature. Qualitative differences in response are anticipated from the case of uniform compression since concentrated loading, such as indentation, acts in the same manner as an initial imperfection in buckling. Our objective is to analyse the sensitivity of the indentation response to impact velocity, for different headshapes and sizes of indenters. Two prismatic headshapes are considered: a flat-bottomed punch (Fig. 2a) and a circular punch (Fig. 2b). For both indenters, velocities varying from quasi-static to 100 m/s are considered. Ship collisions are likely to occur below 10 m/s, whereas the range from 10 to 100 m/s is relevant to land-based transport, such as military, automotive and rail industries.

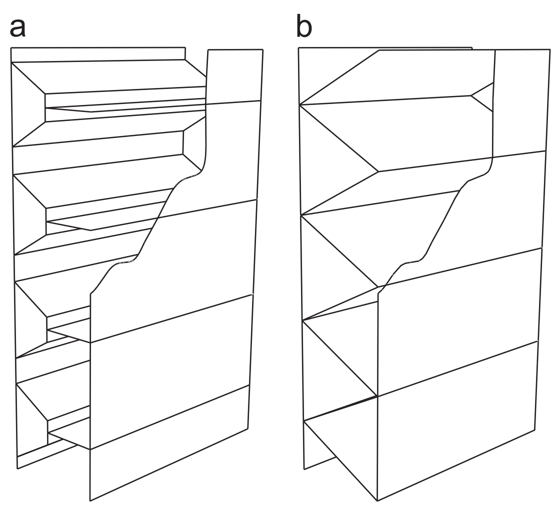

Fig. 1. Sandwich hull designs with (a) a Y-frame core and (b) a corrugated core.

In this study, we compare and contrast the performances of two core designs: the Y-frame and corrugated cores as shown in Fig. 1. To enable a fair comparison, we consider cores of identical mass and overall geometry. While numerous studies have been reported in the literature on other core topologies, such as the I-core [8], the pyramidal core [9–11] and the square honeycomb [12–16], these all use different geometries and masses thereby prohibiting us from making direct comparisons with those alternative designs.

This article is organised as follows. First, a description of the finite element model is given. Second, the dynamic indentation responses and corresponding deformation modes are presented for selected loading velocities. And third, the effects of impact velocity, indenter size and material strain-rate sensitivity upon the dynamic indentation response are explored.

2. Description of the finite element models

The commercial finite element code Abaqus (version 6.11) was used to simulate the quasi-static and dynamic indentation responses of sandwich panels with a corrugated core or a Y-frame core. The finite element models used in this study are based on a considerable amount of previous numerical and experimental work which demonstrated

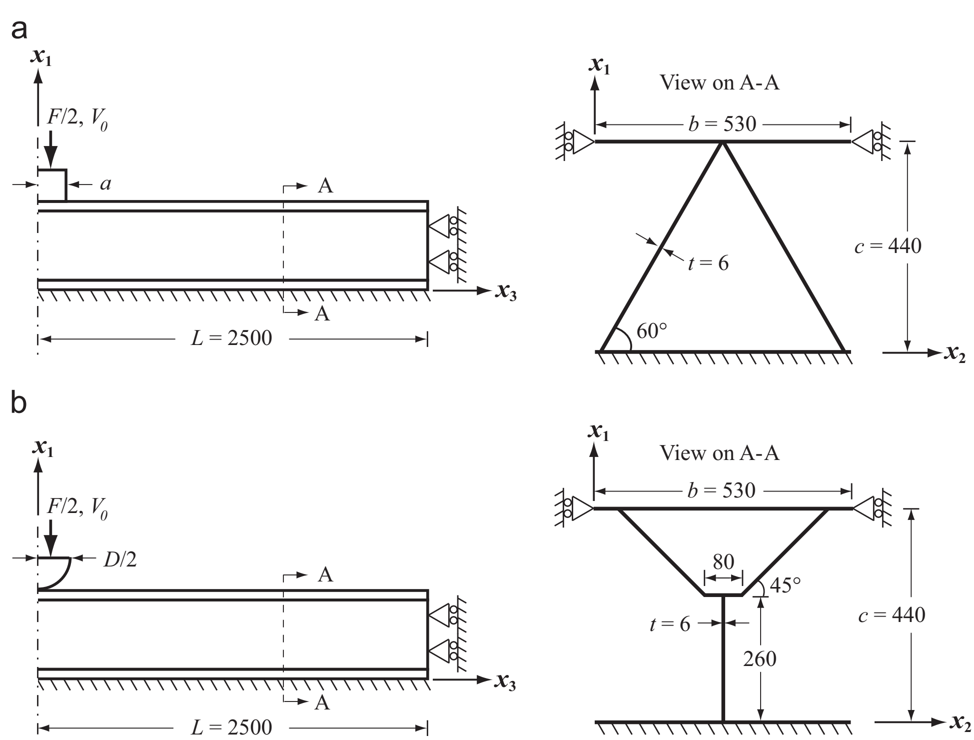

Fig. 2. Dimensions and boundary conditions of (a) a sandwich panel with a corrugated core indented by a flat-bottomed punch and (b) a sandwich panel with a Y-frame core indented by a circular punch. All dimensions are in mm.