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The dynamic response of clamped rectangular Y-frame and corrugated core sandwich plates

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ABSTRACT

The dynamic response of fully clamped, monolithic and sandwich plates of equal areal mass has been measured by loading rectangular plates over a central patch with metal foam projectiles. All plates are made from AISI 304 stainless steel, and the sandwich topologies comprise two identical face-sheets and either Y-frame or corrugated cores. The resistance to shock loading is quantified by the permanent transverse deflection at mid-span of the plates as a function of projectile momentum. At low levels of projectile momentum both types of sandwich plate deflect less than monolithic plates of equal areal mass. However, at higher levels of projectile momentum, the sandwich plates tear while the monolithic plates remain intact. Three-dimensional finite element (FE) calculations adequately predict the measured responses, prior to the onset of tearing. These calculations also reveal that the accumulated plastic strains in the front face of the sandwich plates exceed those in the monolithic plates. These high plastic strains lead to failure of the front face sheets of the sandwich plates at lower values of projectile momentum than for the equivalent monolithic plates.

1. Introduction

Clamped plates are representative of the structures used in the design of commercial and military vehicles. For example, the hull of a ship comprises plates welded to an array of stiffeners. A detailed overview on the shock response of monolithic beams and plates has been given by Jones (1989). More particularly Wang and Hopkins (1954) and Symmonds (1954) have analysed the impulsive response of clamped circular plates and beams. However, their analyses were restricted to small deflections and linear bending kinematics. By direct application of the principle of virtual work for an assumed deformation mode, Jones (1971) presented an approximate solution for simply supported circular monolithic plates undergoing finite deflections. Experiments on impulsively loaded beams and plates have confirmed the deformation modes predicted by these analyses and also revealed a range of failure modes (Menkes and Opat, 1973; Nurick and Shave, 2000). Theoretical studies by Lee and Wierzbicki (2005a, 2005b) have analysed the so-called discing and petalling failure modes in impulsively loaded clamped plates while Balden and Nurick (2005) have analysed the so-called shear rupture modes.

Over the past decade there have been substantial changes in ship design with double hulls and sandwich hulls replacing monolithic plates, see for example the review by Paik (2003). One such innovation has been the Schelde Shipbuilding[1] sandwich design of ship hulls with a Y-frame core, see Fig. 1a. Full-scale ship collision trials reveal that the Y-frame design is more resistant to tearing than conventional monolithic designs, see Wevers and Vredeveldt (1999) and Ludolphy (2001). Likewise, the finite element simulations by Konter et al. (2004) suggest that the Y-frame confers improved perforation resistance. Naar et al. (2002) have argued in broad terms that the ability of the bending-governed Y-frame topology to spread the impact load over a wide area, combined with the high in-plane stretching resistance of the Y-frame, gives the enhanced performance of the Y-frame sandwich construction over conventional single and double hull designs. The corrugated sandwich core (Fig. 1b) is a competing prismatic topology to that of the Y-frame.

Pedersen et al. (2006) and Rubino et al. (2008a) have investigated the quasi-static structural response of Y-frame sandwich beams while Côté et al. (2006) studied the response of sandwich beams with a corrugated core. These studies reveal that geometrical imperfections and/or non-uniform loading (such as indentation loading) induce bending within the struts of the corrugated core and reduce the compressive strength of the corrugated core to approximately that of the Y-frame core. Tilbrook et al. (2007) have performed a combined experimental and numerical investigation into the dynamic compressive response of these cores. They found that buckling of the webs is delayed at low impact velocities by

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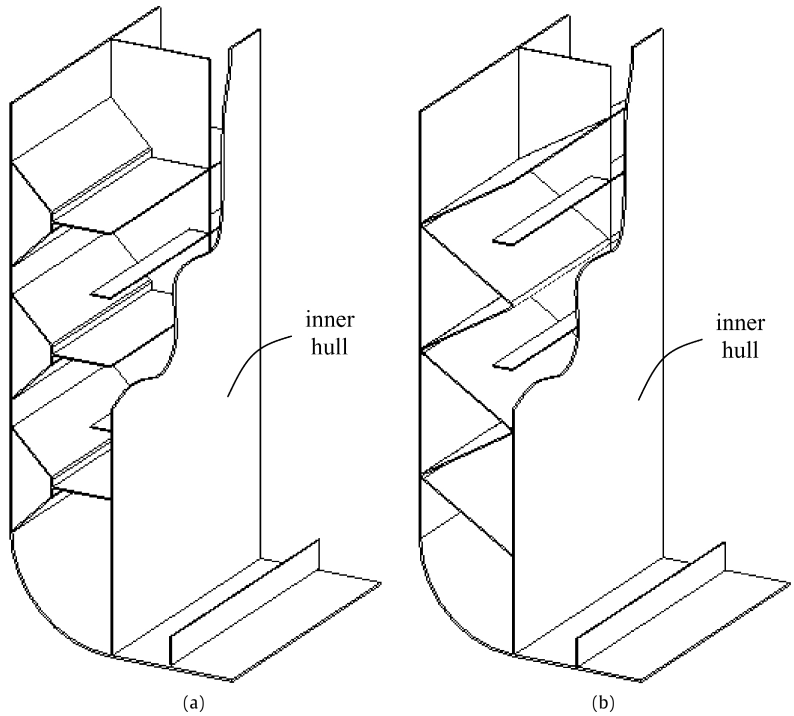

Fig. 1. Sketch of the (a) Y-frame and (b) corrugated sandwich cores as used in ship hull construction. The core is sandwiched between the outer and inner hull of the ship.

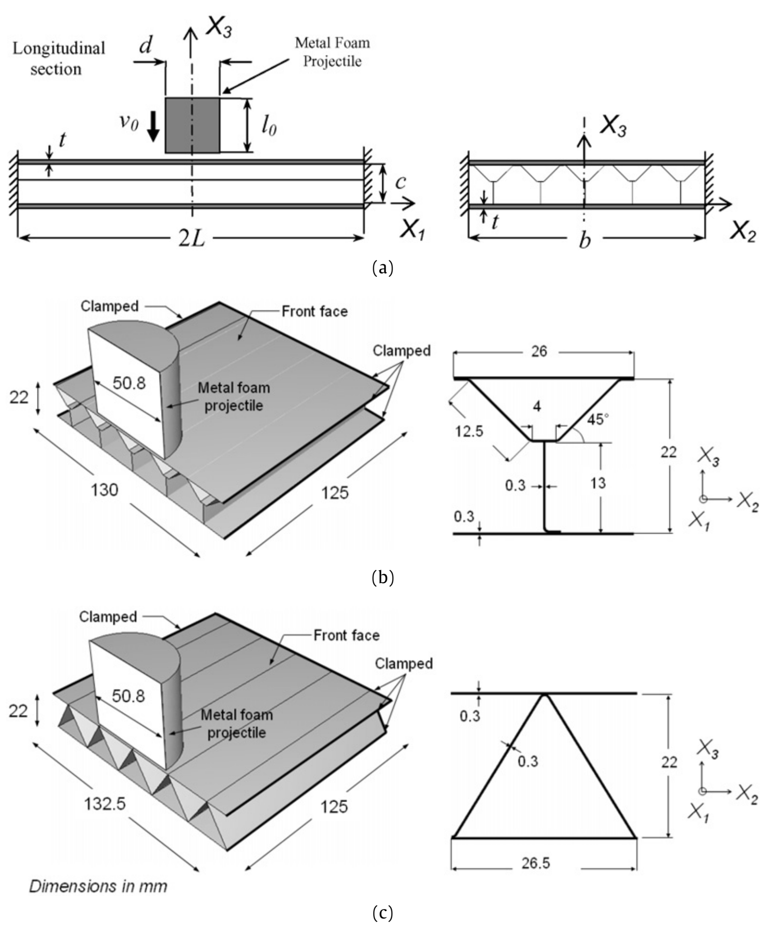

Fig. 2. (a) Sketch of the clamped sandwich plate geometry and the loading arrangement. Geometry of half sandwich plate for (b) Y-frame and (c) corrugated sandwich cores investigated in this study. The cross-section is also shown for each topology. All dimensions are in mm.

inertial stabilisation of the webs while plastic shock wave effects dominate the response at higher impact velocities.

Radford et al. (2005) have developed an experimental technique to subject structures to high intensity pressure pulses using metal