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Crushing response of square aluminium tubes filled with polyurethane foam and aluminium honeycomb

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ABSTRACT

Experimental investigations were conducted to study the axial crushing behaviour of square aluminium tubes with different configurations. Quasi-static compressive loads were applied to square hollow aluminium tubes, aluminium honeycomb-filled tubes, polyurethane foam-filled tubes and aluminium tubes filled with both polyurethane foam and aluminium honeycomb at constant velocities of 0.15 mm/s, 1.5 mm/s and 15 mm/s, respectively. The effects of honeycomb core, polyurethane foam, combined polyurethane foam and honeycomb on the axial crushing behaviour of square aluminium tubes were discussed. The influence of crushing velocity on these different tubular structures was also studied. Experimental results showed that the deformation mode was a progressive folding mode for square hollow aluminium tubes, while it was a splitting mode for square tubes filled with both polyurethane foam and aluminium honeycomb. The fold wavelengths of some typical cases were measured. The most crashworthy combination was found to be square aluminium tubes filled with both polyurethane foam and aluminium honeycomb, where the maximum increases of mean crushing force, energy absorption and specific energy absorption were up to 349%, 334% and 109% respectively, compared with those of hollow tubes.

1. Introduction

Thin-walled structures have been widely used in applications such as aerospace and transportation. For example, one of the most important structural parts in a vehicle is the crumple zone which is usually made from thin-walled metal tubes. These thin-walled structures are preferable in vehicles because they are excellent at dissipating impact energy by a stable progressive deformation when subjected to axial compressive loads.

Previous studies are focused on investigating the effects of structural geometry on energy absorbers as part of a vehicle's crushing system. Yamashita et al. [1], Zhang and Huh [2], Nia and Hamedani [3], Zhang and Zhang [4] and Lu and Yu [5] found that crushing strength and energy absorption increased with the number of corners for metallic polygonal axially loaded tubes. Zhang et al. [6] and Yin et al. [7,8] showed that the energy absorption and the number of folds increased with the number of cells in multi-cell metallic structures.

Several methods have been tried to improve structural energy absorption. One of these methods is filling the tubular structures with lightweight materials such as aluminium honeycomb, metallic foam or polymeric foam. Aluminium honeycomb is a thin-walled multi-cellular structure with high strength to weight ratio. The crashworthiness of metallic honeycomb has been extensively investigated. Wierzbicki [9] derived a theoretical model to predict the crushing behaviour and folding wavelength of hexagonal metallic honeycomb subjected to axial impact loads. He found that the axial crushing strength of honeycomb depended on the honeycomb wall thickness to side length ratio (t/l) and the yield stress of the metal. Xu et al. [10] experimentally investigated the effects of strain rate, cell size, wall thickness to side length ratio (t/l) and the number of cells for different aluminium honeycomb configurations (AA5052-H39) subjected to constant quasi-static and dynamic compressive loads. They found that the plateau stress increased with increasing honeycomb density and strain rate.

Foam is a cellular structure with high porosity. Some examples of foams are aluminium foam, polyurethane foam and polystyrene foam. There are a wide range of densities of these foams depending on their cell sizes. Quasi-static and low velocity impact loadings of different aluminium honeycomb specimens filled with different polyurethane

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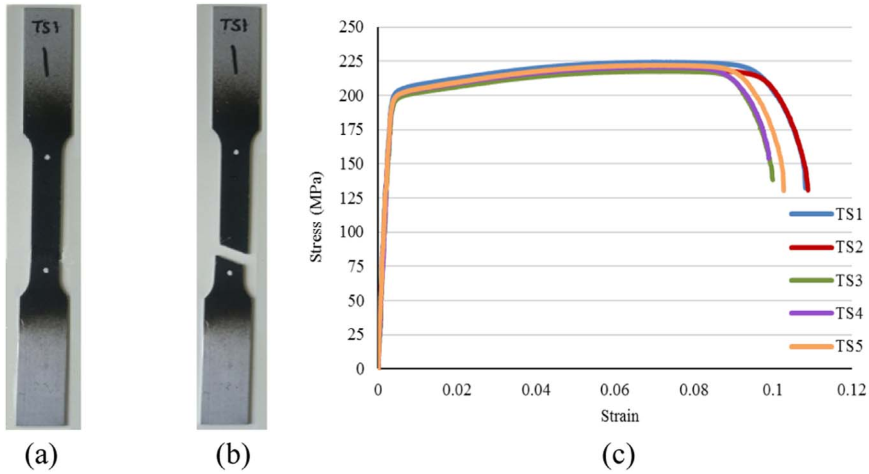

Fig. 1. (a) A photograph of a tensile coupon before test; (b) a photograph of a tensile coupon after failure; (c) engineering stress-strain curves of aluminium coupons from tensile tests.

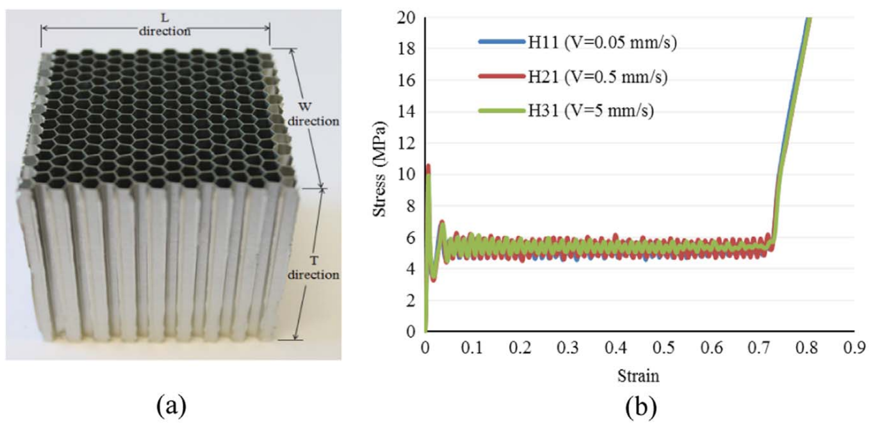

Fig. 2. (a) A photograph of an aluminium honeycomb specimen; (b) stress-strain curves of honeycomb specimens tested at three different compressive velocities [19].

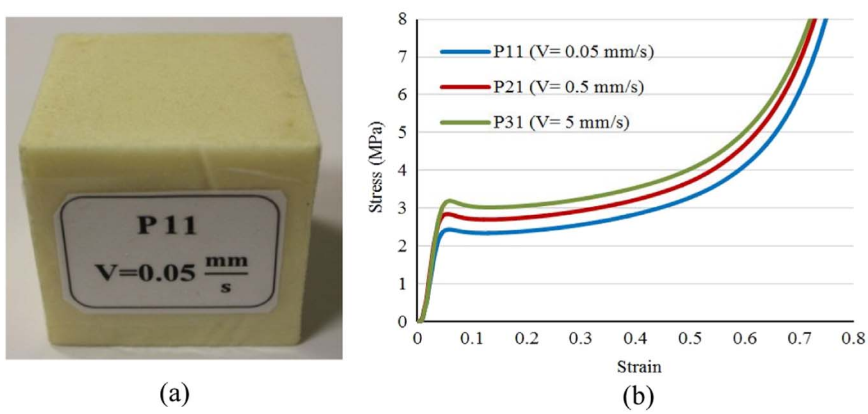

Fig. 3. (a) A photograph of a polyurethane foam specimen; (b) stress-strain curves of polyurethane foam specimens tested at three different compressive velocities.

Table 1
Specimen groups.

Group no	Designation	Details
1	AST	Square hollow aluminium tubes
2	ASTH	Honeycomb-filled square aluminium tubes
3	ASTP	Polyurethane foam-filled square aluminium tubes
4	ASTHP	Polyurethane foam and honeycomb-filled square aluminium tubes

foams were investigated by Mahmoudabadi and Sadighi [11]. These authors found that the increases of mean crushing forces (MCF) of polyurethane foam-filled aluminium honeycomb were from 10% up to 145% which was more than the sum of mean crushing forces for polyurethane foam and hollow honeycomb, depending on polyurethane foam and aluminium honeycomb densities. However, the fold wave-length of the filled honeycomb decreased with increasing polyurethane foam density [11].

Theoretical and numerical investigations of aluminium honeycomb and aluminium foam filled thin-walled square aluminium tubes under axial compressive loads were conducted by Santosa and Wierzbicki [12]. The square tubes have a side length of 80 mm and height of