Thin-Walled Structures 132 (2018) 667–681

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Crushing response of square aluminium column filled with carbon fibre tubes and aluminium honeycomb

G. Balaji, K. Annamalai*

School of Mechanical and Building Sciences, Vellore Institute of Technology, Chennai 600127, India

ARTICLE INFO

Keywords:
Honeycomb
Carbon fibre
Aluminium column
Crushing behaviour
Energy absorption

ABSTRACT

Experimental and numerical evaluation is performed on a square hollow aluminium column, an aluminium honeycomb filled column, an aluminium column filled with combined carbon fibre and an aluminium honeycomb at constant velocity of 3.06 mm/s to analyze the axial crushing phenomenon at low speed axial loads. To validate experimental outputs, numerical simulation is performed using PAMCRASH explicit finite element code. The effects of honeycomb core and carbon fibre reinforced aluminium honeycomb were analysed experimentally and numerically. A decent agreement between experimental and numerical results is observed. The effects of deformation modes and force-displacement curves on these different structural columns were studied. Experimental and numerical results showed the square aluminium column filled with carbon fibre reinforced aluminium honeycomb was the most crashworthy combination, where the maximum increase of energy absorption, specific energy absorption and crush force efficiency were up to 60.6%, 27.8% and 17.4% respectively, compared with bare aluminium hollow column.

1. Introduction

Thin-walled structures play a key role in ensuring the maximum level of advantage for structural design engineers of aerospace and automobile applications. For example, the structural region with the largest influence in an automotive vehicle is the crush zone which is generally made of thin-walled metal columns. The important structures in vehicle accountable for impact energy absorption at the time of frontal impacts are the longitudinal members which are also called front side members. In general, most of the side members are thin-walled structures with hollow tubular rectangular or square cross section that ejects impact energy by plastic deformation. Thin-walled structures are more advisable for vehicles due to their outstanding performance in dematerializing the impact energy by a uniform progressive crushing mode when exposed to axial compressive loads [1]. Thin-walled structures are recommended for improved crashworthiness and superior energy absorption applications due to their elevated energy absorption efficiency and light weight [2].

The focus of investigation so far has been the analysis on the effects of structural geometry on the energy absorption at compressive loadings. A new U-shaped thin plate energy absorber was proposed by Liu et al. [3] and concluded that increasing the thickness and friction coefficients of the plate improves the energy absorption. Qureshi et al. [4] studied embedded sinusoidal patterned beams with conventional notch triggers and progressive frequency triggers under oblique loading and concluded that the beams with progressive triggering can be a better alternative for plain beams. Ying et al. [5] investigated thin-walled high strength steel with functionally graded strength (FGS) and uniform strength (US) column for axial crushing and oblique impact loading numerically and observed that, FGS column exhibiting crash performance better than the US ones due to the double-direction variation of top strength and gradient exponent. Sun et al. [6] analysed the axial functionally graded thickness (AFGT), lateral functionally graded thickness (LFGT) and uniform thickness (UT) thin-walled structures of square shape for crashworthiness under axial crushing load and found the AFGT square tube effectively reducing the initial peak force compared to that of UT square tube, whereas LFGT square tube effected a remarkable increase in the specific energy absorption compared to UT square tube under axial crushing loads. Crashworthiness of single and multi-cell square structures for axial loads was the subject matter of investigation for Xie et al. [7] who acknowledged the response surface models of the structures using polynomial response surface method (PRSM). The influence was that, the increase in the number of cells of structure causes a decrease in the radius of folds and an increase in specific energy absorption was observed with increase in wall thickness and decrease in side-length. Xie et al. [8] employed single objective

* Corresponding author.
E-mail address: kannamalai@vit.ac.in (K. Annamalai).

https://doi.org/10.1016/j.tws.2018.07.037
Received 6 April 2018; Received in revised form 8 July 2018; Accepted 23 July 2018
0263-8231/

particle swarm optimisation (SOPSO) model and multi-objective particle swarm optimisation (MOPSO) model to optimize specific energy absorption and initial peak force of coupled thin-walled metal and aluminium honeycomb composite structure.

Xie et al. [9] adopted simplified super folding element theory to derive mean crushing force and specific energy absorption ratio for five various multi-cell square tubes by considering side-length and section form parameters and concluded that section form has reasonable impact on crushing force and specific energy absorption. Chiu and Jenq [10] examined the axial compression behaviour of aluminium thin-wall structures with certain through-hole triggering mechanisms and found 1.7% decrease in the initial peak force for the structures with a pair of circular holes compared to square tubes without holes.

Numerous techniques have been practiced for enhancement of the energy absorption of the structural component. One of the well adopted methods is the use of lightweight filler materials such as metallic foam, conventional foam, polyurethane foam, carbon fibre reinforced polymer, fibre reinforced polyethylene matrix and aluminium honeycomb cores inside the hollow tubular structures. Aluminium honeycomb is light weight, thin-walled and typical multi-cellular construction with a good strength to weight ratio. The compressive behaviour of aluminium honeycomb has been substantially investigated in the previous studies for the crashworthiness parameters. Hussein et al. [1] experimented quasi-static axial crushing response of square aluminium columns filled with aluminium honeycomb, polyurethane foam and aluminium columns filled with both aluminium honeycomb and polyurethane foam at a persistent velocity of 0.15 mm/s, 1.5 mm/s and 15 mm/s respectively and proved that square aluminium tubes filled with both polyurethane foam and aluminium honeycomb increases energy absorption, mean crushing force and specific energy absorption up to 349%, 334% and 109% respectively compared to hollow aluminium tubes. Niknejad et al. [11] analysed energy absorption, initial peak force and mean folding force in empty and polyurethane foam-filled grooved circular tubes and concluded that foam-filled grooved circular tubes exhibited encouraging results compared to the simple empty tubes. To explicate the design methodology Gan et al. [12] analysed circular, hexagonal and square carbon fibre reinforced plastics, tapered thin-walled aluminium alloy tube, aluminium foam and polyurethane foam (PU foam) filled structures for quasi-static axial compressive loading and judged that PU foam-filled CFRP tapered tube is a prospective composition for energy absorption and light weight design.

Mozafari et al. [13] verified numerically three various polyurethane foams and compared the results with empty honeycomb cores and proposed that foam filled aluminium honeycomb drastically diminishes PCF (Peak Crush Force) magnitude and accelerates SAE (Specific Energy Absorption) in all combinations. Wang et al. [14] performed comprehensive investigation by numerically and experimentally with honeycomb filled thin square walled tube (HFST) structures for crashworthiness characteristics and concluded that embedding honeycomb filler produce a higher peak force for the first buckling and exhibits a constant strength at the plateau region. Liu et al. [15] conducted experiments on quasi-static axial compression of carbon fibre reinforced plastic (CFRP) square tubes filled with aluminium honeycomb and found that the peak load response and energy absorption of filled tubes increased by 10% with that of bare CFRP tubes, nearly from 12.41% to 27.22% and from 10.49% to 21.83% respectively. Petrone et al. [16] worked on the low velocity impact analysis of continuous-unidirectional fibre incorporated polyethylene honeycomb cores and short-random fibre incorporated polyethylene honeycomb cores for a change in energy absorption and concluded that the cores made of continuous fibre reinforced composites produced superior results.

Carbon fibre reinforced polymer (CFRP) is a sturdy and light weight plastic material which is incorporated with carbon fibre. CFRP is conventionally used for high strength-to-weight ratio and rigidity applications, particularly in automotive and aerospace applications. Hussein et al. [17] experimentally studied hollow tubes of square carbon fibre reinforced plastic (CFRP) and aluminium sheet enveloped CFRP tubes for axial quasi-static loading with notches and concluded that aluminium sheet enveloped CFRP tube with notches exhibited better performance than that of flat platens. Xu et al. [18] made experimental analysis of various types of CFRP tubes fabricated using the filament winding technology for crashworthiness response and saw that hybrid carbon/aramid fibre reinforced polymer tubes showcased the highest energy absorption of 98 kJ/kg in quasi-static loading condition and 82 kJ/kg in dynamic loading condition. Energy absorption capability of carbon-epoxy and glass-epoxy composite tubes and truncated cone shapes were analysed by Ochelski and Gotowicki [19]. The authors found 20% superiority for the energy absorption proficiency of the carbon epoxy composite over the glass epoxy composite. Abdewi et al. [20] studied the crushing behaviour of woven roving glass fibre/epoxy laminated composite tubes of various types like radial corrugated, cylindrical and corrugated surrounded by cylindrical tubes and concluded that the cylindrical type composite tube presented a notable improvement compared to other classifications in different loading conditions. To derive the best possible structural combination, Sun et al. [21] compared the crashworthiness ability of empty circular carbon fibre reinforced plastics with CFRP/aluminium/steel tubes filled with aluminium foam or aluminium honeycomb for axial quasi-static loading and found that specific energy absorption of foam-filled CFRP tubes are superior than those of the metallic structures. The crushing response, collapse modes and crashworthiness behaviour of CFRP tubes were analysed by Mamalis et. al. [22] under a static axial loading condition for understanding the effect of geometric parameters like axial length, aspect ratio and wall thickness and concluded that the progressive stable end-crushing mode conveyed a better crash energy absorption. Hamada et al. [23] compared the crashworthiness behaviour of carbon fibre/epoxy and carbon fibre/PEEK tubes with that of fibre orientations of unidirectional parallel 0°, +30° and +45°. The authors proved that the 0° carbon fibre/PEEK tubes had highest specific energy absorption of 180 kJ/kg.

However, to the best of the authors knowledge, there has been no report in literature on the experimentation of the axial quasi static crushing response of square aluminium column filled with both aluminium honeycomb and CFRP circular tubes. A new technique of concrete filled fibre reinforced polymer tube (CFFT) was experimentally investigated by Khan et al. [24] for axial compression loading. Two types of CFFT samples namely carbon FRP (CFRP) tube and glass FRP (GFRP) tube was analysed and concluded that CFRP CFFT samples and GFRP CFFT samples was almost similar in concrete strengths and concrete axial strains. The railway vehicle's front-end composite energy absorbing structure was numerically analysed by Xie et al. [25] which was designed by thin walled metal structure and honeycomb for quasi static loading and concluded that by improving the plateau stress of the honeycomb will increase the energy dissipating capability of the overall structure. The Kriging surrogate model optimisation model was successfully adopted by Xie et al. [26] to optimize the specific energy absorption (SEA) and ratio of specific energy absorption to initial peak force(REAF) parameters of circumscribed circle and inscribed circle composite structures. Also, it was concluded numerically that circumscribed circle sample has a remarkable energy-absorbing ability and less initial peak force.

In this research work, the crashworthiness phenomena of an aluminium square column, an aluminium honeycomb-filled square column and aluminium square column filled with both carbon fibre tubes and an aluminium honeycomb were experimentally investigated. These columns were compressed with an axial constant velocity of 3.06 mm/s by using a 200 kN UTM machine. The influences of honeycomb, carbon fibre, a combination of carbon fibre and honeycomb filling on the crashworthiness of square aluminium column was analysed. Deformation mode, initial peak force (IPF) energy absorption (EA), specific energy absorption (SEA) and crush force efficiency (CFE) of