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Influences of different internal stiffeners on energy absorption behavior of square sections during the flattening process

Pedram Khanchehzar [a], Abbas Niknejad [b,*], Seyed Ghaem Amirhosseini [b]

[a] Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[b] Mechanical Engineering Department, Yasouj University, P.O. Box: 75914-353, Yasouj, Iran

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ABSTRACT

The present article introduces some novel patterns of internal blades as the stiffener into thin-walled square aluminum sections to enhance energy absorption behavior of reinforced structures under the lateral loading by the experimental methods. To prepare the specimens, a thin-walled square columns made of aluminum with external cross-sectional dimensions of 34.4 mm × 34.4 mm were prepared and cut to the constant nominal length of 40 mm. Then, some internal blades with thickness of 1.25 mm were prepared and after the shaping process, the formed blades were positioned into the square specimens by the point-welding. The manufactured specimens were positioned between two rigid platens and the quasi-static lateral load was performed on the specimens and the samples were laterally compressed in the flattening process. Furthermore, a simple square specimen without any stiffener was used in the lateral compressed test and its energy absorption capacity and specific absorbed energy were measured as the benchmark. The experiments show that by reinforcing the thin-walled square section with the internal blades, a new structure is achieved that can absorb the kinetic energy up to 2.99 times of the simple square section of the benchmark. In addition, according to the results, it is found that absorbed energy/mass ratio of the best reinforced specimen is 1.92 times of the benchmark.

1. Introduction

Thin-walled sections such as tubes and columns are often subjected to heavy accidental transverse loads, which may cause significant damage, and their ability to absorb the kinetic energy of applied loads and transform it into plastic deformations is of particular interest in numerous practical engineering applications [1]. Alghamdi [2] reviewed common shapes of collapsible energy absorbers such as circular tubes, square tubes, frusta, struts, honeycombs, and sandwich plates during different modes of deformation such as axial crushing, lateral indentation, lateral flattening, inversion and splitting.

Reddy and Reid [3] laterally compressed some circular metal tubes between two horizontal rigid platens on the top and bottom of the samples and with left and right side constrains so that their horizontal diameter remains constant during the test. Wu and Carney [4] conducted a series of experiments on braced, elliptical tubes with semi-axes ratios between 0.5 and 2 under lateral compression; and verified predictions of theoretical analysis. England and Gregory [5] investigated deformations of an elastic-plastic tube compressed between two rigid smooth parallel plates.

Gupta and Abbas [6] performed some experiments on composite tubes with different diameters and wall thicknesses under the lateral crushing by a constant loading rate of 2 mm/min. Also, a few tests were conducted on similar tubes under the impact of a drop hammer at a speed of 4.4 m/s. They found that deformation modes of both types of the tests are similar. Zeinoddini et al. [7] derived a closed analytical solution for response of tubes subjected to lateral quasi-static or dynamic impact loads. They found that by assuming a rigid-perfectly plastic behavior for the ring resistance, accurate results for long tubes are obtained. Gupta et al. [8] presented an experimental and computational study on rectangular and square tubes made of aluminum and mild steel and subjected to quasi-static transverse loading. Deformed shapes at different stages, load-compression and energy-compression curves were obtained, experimentally. Nemat-Alla [9] introduced a simple technique to identify stress-strain behavior in circumferential direction for tubular materials, based on experimental data obtained from tube lateral compression test.

Brooker [10] simulated the quasi-static lateral indentation of tubes supported continuously along their base and fully restrained at each end, using the finite element method. A parametric study considering the influence of wall thickness, tube length, diameter and yield stress was described and an equation for predicting the

* Corresponding author.
E-mail address: Aniknejad@yu.ac.ir (A. Niknejad).

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permanent dent depth for a given load was derived. Karamanos and Eleftheriadis [1] investigated collapse of circular tubes under lateral quasi-static loading in the presence of uniform pressure. They investigated pressure effects on ultimate lateral load of tubes and on their energy absorption capacity. Calme et al. [11] evaluated energy absorption and mechanical behavior of composite rings during the flattening process between two flat platens. An analytical modeling of elastic stress state inside moulded composite cylinders by resin transfer moulding process (RTM) under lateral compression was presented by Calme et al. [12]. Experimental analysis described the quasi-static delamination under lateral compression of RTM-moulded carbon-epoxy rings. Morris et al. [13] conducted numerical and experimental analyses on quasi-static lateral compression process of nested metal tubes with vertical and inclined side constraints subjected to the applied compressive loading by different parts such as a rigid platen and two different indenters.

Karamanos and Andreadakis [14] presented the structural response of tubular members subjected to lateral quasi-static loading, imposed by wedge-shaped denting devices, in the presence of internal pressure by numerical and theoretical methods. They found that the presence of internal pressure significantly increases the denting force. Morris et al. [15] introduced rings/tubes as suitable parts that are low in cost and are readily available for selection in the design process. They mentioned that the function of such a device is to bring a moving mass to a controlled stop and ideally cause the occupant ride down deceleration to be within acceptable limits so as to avoid injuries or to protect delicate structures. Also, they showed that an energy absorbing device may consist of a system of rings/tubes that are compressed laterally which absorbs the kinetic energy upon impact and dissipating it as plastic work. Elfetori et al. [16] presented effects of corrugation geometry on crushing behavior, energy absorption, failure mechanism and failure mode of laminated composite tubes subjected to axial and lateral compressive loadings. Mahdi and Kadi [17] used artificial neural networks technique to predict crushing behavior and energy absorption characteristics of laterally loaded composite elliptical tubes. Predicted results were compared with actual experimental data in terms of load carrying capacity and energy absorption capability.

Dynamic lateral crushing of mild steel nested tubes was conducted using an impact tester by Olabi et al. [18]. The tests were performed with impact velocities ranging between 3 and 5 m/s. Their crushing behavior and energy absorption capabilities were obtained and analyzed. Olabi et al. [19] analyzed crushing behavior and energy absorption capabilities of two arrangements of nested tube systems consist of one standard and one optimized design subjected to dynamic lateral loading by experimental and numerical methods. Fan et al. [20] conducted the systematic investigations into sandwiched thin-walled circular tubes by aluminum foam under quasi-static lateral crushing. Guoyun et al. [21] conducted numerical simulation of lateral impact cases of liquid-filled tube impacted by missiles by a commercial finite element code LS-DYNA, and obtained results were compared with experimental data to verify the validity of the numerical simulation model. Fan et al. [22] examined dynamic lateral crushing behavior of short empty and sandwich circular tubes. Unlike the conventional impact method, the specimens were placed on the bottom platen of an Instron machine with a constant upwards velocity and then, the tube collided with the fixed upper rigid platen. To accurately and rapidly identify material parameters of thin-walled tube under compressive stress state, a hybrid inverse identification method was proposed by Liu et al. [23], based on tube lateral compression test with combining finite element simulation, regression analysis and genetic algorithm. Niknejad et al. [24] presented a theoretical and experimental study on lateral compression of square and rectangular metal columns between two rigid platens. They derived some theoretical relations to predict absorbed energy, specific absorbed energy and lateral load of the columns during the flattening process. Niknejad and Rahmani [25] introduced a simple analytical model of plastic deformation of hexagonal metal columns during the lateral flattening process in the quasi-static condition. Based on the introduced model, some theoretical relations were derived to forecast average and instantaneous lateral load of hexagonal columns in the empty and polyurethane foam-filled conditions. Baroutaji et al. [26] used some circular tubes with outer diameter of 101.6 mm, wall thickness of 3.25 mm and length of 40 mm; and by using suitable fixtures and subjecting the cylindrical tubes to opposing tension forces, the tubes were transformed into oblong curve profile. Then, the oblong tubes were laterally compressed between different platens and indenters to investigate their energy absorption behavior during the flattening and indentation processes. Then, Baroutaji et al. [27] suggested sandwich tubes consist of thin-walled circular tubes with aluminum foam core as an energy absorber system. The sandwich tubes were laterally crushed under quasi-static loading by the experimental and finite element methods to assess their energy absorption responses and deformation modes. Tavassolimanesh et al. [28] presented an experimental analysis on circular composite tubes under the quasi-static lateral compression loading during the flattening process in three different filling conditions: empty, polyethylene, and polyurethane Teflon-filled. Energy absorption behavior and failure response of the tubes during the flattening tests were studied. Baroutaji et al. [29] studied responses of circular nested tube systems under quasi-static and dynamic lateral loading. Nested systems in the form of short internally stacked tubes were proposed as energy absorbing structures. Niknejad and Orojloo [30] introduced a thin-walled specimen with longitudinal grooved section as an energy absorber during the flattening process. They examined lateral compression process and energy absorption behavior of grooved sections with special cross-section between two rigid platens. Influences of presence of polyurethane foam-filler and nesting the section by aluminum or brazen tube were studied on energy absorption capability by the structure under the quasi-static lateral loading.

Thin-walled sections are widely used in different applications such as automotive frame and structure and in some situations; external loads in the lateral direction are applied on them. Sometimes, their energy absorption capacity is small, comparing with their energy absorption under the axial loading. This article introduces a novel method for solving the mentioned problem or reducing its undesirable effects. In this article, several different types of simple and formed blades are designed and positioned into thin-walled specimens with square cross-sections to investigate effects of internal stiffeners on energy absorption behavior of the structure subjected to the quasi-static lateral loading during the flattening process.

2. Experiment

In the present research work, influences of different internal stiffeners on energy absorption behavior of square sections during the flattening process are investigated, experimentally. For this purpose, some square specimens made of aluminum alloys were prepared and reinforced by different models of stiffeners. Table 1 represents geometrical parameters of square tubes. In the table, L and t are nominal length and wall thickness of the tubes.

Investigation of influences of geometrical shape of internal stiffeners is the main goal of the present article. Therefore, all the internal stiffeners were prepared by performing the cutting