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Technical Report

Geometrical discontinuities effects on lateral crushing and energy absorption of tubular structures

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ABSTRACT

This research involves the experimental study of lateral flattening of tubular structures. Main goals are investigations of the effects of geometrical discontinuities on energy absorption characteristics of these structures and finding new ways for increasing the energy absorption capacities. Three groups of specimens were investigated: square and rectangular aluminum columns, circular brazen tubes and circular composite tubes where some notches of different lengths were created on various positions of them. The specimens were compressed between two rigid plates during a quasi-static process and their energy absorption parameters were calculated using the testing machine's data. Experimental results show that numbers of notches on walls of the structures may increase or decrease their energy absorption capability, depending on the notches positions. Square columns with notches on up and down sides are cases in which the amounts of energy absorption are more than their corresponding intact specimens. In most of the specimens, notches lengths had reverse relation with their energy absorption. Behaviors of composite tubes under lateral compression loading are more sensitive to the notches lengths than the other specimens. By changing the notches positions on walls of the specimens, the deformation mode and consequently the energy absorption capability can be determined which is the case that is studied in this research.

1. Introduction

Due to advances in transport technology, there has been a noticeable increase in the number of transportation vehicles in society. This has fuelled scientist/engineers particularly in the last few decades to research and develop energy absorbers with an objective to attenuate the effect of impact on people and structures. It should be noted that energy absorbers are not only applicable to the transportation sector; but also to other fields of engineering such as nuclear reactors, oil-rigs and oil tankers, crash barriers for roadsides and air-drop cargo [1].

Energy absorbers are systems that convert, totally or partially, kinetic energy into the other forms of energy. The converted energy is divided into two groups: reversible, like pressure energy in compressible fluids and elastic strain energy in solids, and irreversible, like plastic deformation energy. Among different shapes of energy absorbers tubes and columns are the most commonly used structural elements due to their prevalent occurrence and easy manufacturability. Plastic deformation modes of thin-walled tubular structures are characterized into following five groups: inversion, splitting, axial crushing, lateral indentation and also, lateral flattening which is the investigated case in present study [2].

Recently, Niknejad et al. [3–6] studied quasi-static axial deformation of empty and polyurethane foam-filled intact and grooved tubes, theoretically and experimentally. Yan and Chouw [7] investigated crashworthiness characteristics of natural flax fiber reinforced epoxy composite circular tubes from the point of view of energy absorption. They showed that flax fabric reinforced epoxy composite tube has the potential to be a useful energy absorber device. Also, Yan et al. [8] studied effects of polyurethane foam-filler on energy absorption of flax fabric reinforced epoxy composite tubes under axial quasi-static compression. Foam-filled tubes have better crashworthiness than empty tubes in total absorbed energy, specific absorbed energy and crush force efficiency. Mahdi et al. [9] introduced a four-phase program to improve the specific absorbed energy by axially crushed composite collapsible tubular energy absorber devices. Zhang et al. [10] studied design issue of thin-walled bi-tubal column structures that were filled by aluminum foam under axial compression, numerically and experimentally.

Also, some researchers investigated effects of different geometrical imperfections on axial crushing of thin-walled tubular structures. Arnold and Altenhof [11] examined the effects geometrical imperfections in the form of circular holes, on the crashworthiness

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characteristics of axially loaded extruded aluminum tubes. The experiments resulted that circular discontinuities cause increment of the crush force and even large increment of energy absorption. Cheng et al. [12] investigated axial crush behavior of square aluminum tubes with different circular, slotted and elliptical discontinuities. The results of their research show that by introducing crush initiators into the structural members, the splitting and cutting deformation modes were generated rather than global bending deformation which was observed for specimens without any discontinuities. Alavi Nia et al. [13] studied the effects of cracks on mechanical behavior of cylindrical and square thin-walled aluminum tubes under the quasi-static axial compression. They found that the cracks change collapse processes, folding modes and energy absorption parameters of thin-walled tubular structures under axial compression.

Reid and Reddy [14–19] performed vast theoretical and experimental researches on flattening of thin-walled tubes. They investigated the effects of strain hardening, side constraints, and inertia on lateral impact of metal rings in free and fixed-ended systems. Gupta and Sinha [20] studied lateral collapse behavior of square tubes, placed orthogonally in two layers and sandwiched between two rigid platens, experimentally. Gupta and Abbas [21] introduced some theoretical relations for predicting mechanical parameters in the flattening process of composite tubes and compared the results with experimental tests. Experimental and computational studies of rectangular and square tubes made of aluminum and mild steel and subjected to quasi-static transverse loading were presented by Gupta et al. [22]. Morris et al. [23,24] presented numerical and experimental researches on lateral compression of nested circular and elliptical tubes with and without indenters and exterior constraints. In recent years, some researches studied the lateral compression of foam-filled metal and composite tubes with different cross-sections. Niknejad et al. [25–27] examined quasi-static lateral deformation of empty and polyurethane foam-filled brazen, aluminum and composite tubes and columns with different geometrical characteristics. Their experimental results showed that the polyurethane foam-filler increases energy absorption capability by the specimens. Also, some theoretical relations are presented by Niknejad et al. [27] to predict load–displacement and energy-displacement diagrams of empty rectangular columns. Mahdi and Hamouda [28] presented an extensive experimental investigation of in-plane lateral crushing of composite hexagonal ring system between flat platens. Liu et al. [29] introduced a new hybrid identification method for determining material parameters of thin-walled tubes under lateral and axial compressive stress state. Niknejad et al. [30] estimated some theoretical relations that predict variations of the lateral load in terms of lateral displacement for empty and foam-filled hexagonal tubes under quasi-static lateral compression and compared the results with experiments. Yan et al. [31] compared energy absorption capacities of empty and foam filled natural flax fiber reinforced composite tubes with the existing circular empty and/or foam filled tubes made of metallic materials and synthetic fiber reinforced composites. They resulted that with a proper design, the specific energy of natural flax fiber reinforced composite tubes can be close and/or comparable to that of aluminum and glass/carbon fiber reinforced composite tubes as energy absorbers.

Novelty of current research is study of quasi-static lateral crushing of circular brazen and composite tubes and also, square and rectangular aluminum columns with geometrical discontinuities in the form of notches. Effects of different notches are investigated on deformation modes and energy absorption parameters of the specimens. Actually in some applications creation of discontinuities on walls of the energy absorbers is mandatory, e.g. in place of connections. Targets of this research are finding the best positions for discontinuities on walls of energy absorbers in order to reduce their negative effects on the absorbed energy and even finding ways for making the notches effect positively.

2. Experimental procedure

This research focuses on the deformation modes and energy absorption parameters of notched thin-walled structures. Several specimens in three groups of square and rectangular aluminum columns, circular brazen tubes and circular composite tubes were prepared and different through-thickness notches were created on the specimens' walls. The notches were created by 1 mm and 2 mm end mills using a vertical milling machine. Besides, some intact specimens were prepared. Totally, 82 tubes and columns were laterally compressed between two rigid platens in a Zwick testing machine. Speed of crosshead was kept at 10 mm/min, in all tests.

2.1. Square and rectangular aluminum columns

The specimens were cut out of commercially available aluminum columns with square and rectangular cross-sections. Totally, 19 square columns and 14 rectangular columns were prepared and tested. Cross-section (height × width) and wall thickness of square columns were 35 × 35 mm and 1.5 mm, and those of rectangular columns were 64 × 25 mm and 2 mm, respectively. Some axial notches of different lengths and width of 1 mm were created on the specimens edges. Also, some intact specimens with same

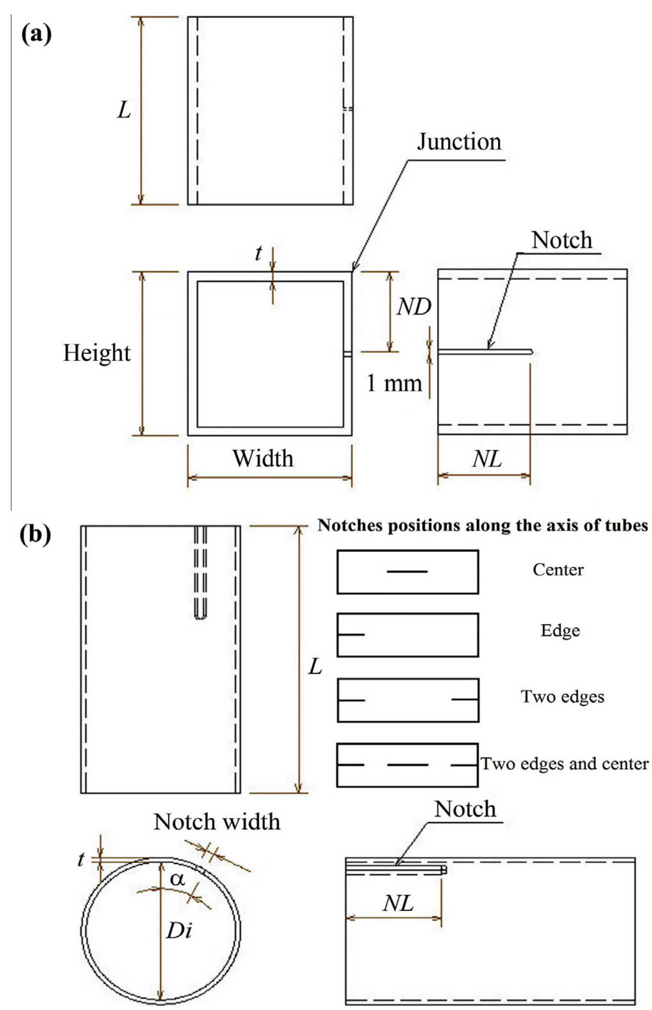

Fig. 1. Geometrical characteristics of, (a) columns and (b) tubes.