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# The effect of radial distance of concentric thin-walled tubes on their energy absorption capability under axial dynamic and quasi-static loading

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ABSTRACT

This study investigates the effect of radial distance of concentric thin-walled tubes on their energy absorption capability through simulation by LS-Dyna finite element software and experimental tests. Concentric cylindrical tubes made of aluminum 1050 with different radii were exposed to axial dynamic and quasi-static loading and optimum radial distance in maximum energy absorption condition was obtained. In overall, 24 states for simulation and 8 states for experimental tests have been investigated. Dynamic loading has been applied in form of hitting of a 75 kg mass with speed of 8 m/s and quasi-static loading of the structures has been done with speed of 150 mm/min and elongated to 70% of the initial length of tubes. Comparison of results of the two concentric tubes and single-tube system with equal mass of structures showed that energy absorption of two-tube system is more than single-tube system. Furthermore, in concentric tubes' system, in the state where the distance of both tubes has changed, the energy absorption is more than the state where the radius of the outer tube is constant and just the radius of the inner tube changes.



## 1. Introduction

Development and analysis of energy absorbent structures is one of the main issues in impact management. Thin-wall aluminum tubes in various dimensions and forms are widely used as a big group of energy absorbers in vehicles. At the time of designing such structures, the study of mechanical behavior, energy absorption and their crumpling is essential. Thus, the tubes under axial and lateral loadings have been the main title of most studies in recent decades. Reid [1] has studied the specification of some metal pieces that are considered as energy absorbers of impact and deformation modes due to axial pressure. Furthermore, the buckling of tubes with square section that were filled with poly-urethane foam has been discussed. In the Juning Sun study [2], the energy absorption specification of extruded tubes has been studied using LS-Dyna finite element code. The results of this study showed that the extruded tubes with circular and hexagonal sections have high energy absorption efficiency compared to triangular sections and the extruded tube of triangle has the lowest maximum crushing force. In Syed Kamruzzaman [3] study, ABAQUS software has been used for computational electrodynamics modeling in buckling. The aim of this study is to investigate the effects of geometry, material and impact condition for computational electrodynamics modeling in buckling. The aim of this study is to investigate the effects of geometry, material and impact conditions on energy absorption of T-form joints made from tube. The results of this study showed that for these joints, in higher maximum force, higher thickness of material is needed and when the impact speed increases, folding distance also increases. Furthermore, it was specified that the type of material has significant role in efficiency of energy absorption of these joints and concerning the energy absorption efficiency, a desired height of horizontal member of T-form joint was obtained. In Alghamdi study [4], the common shapes of flexible energy absorbers and various deformation states have been studied. These shapes include cylindrical tubes, square tubes, frustum, metal foams, and honeycomb and sandwich plates. Furthermore, the common deformation states for cylindrical tubes were axial rupture, lateral indentation, lateral bending, buckling and splitting.

Abramowicz [5] designed key structural components of most transportation devices as thin-wall components. During an accident, some of the structural components should be maintained, at the same time, other components should dissipate the impact energy in a controlled way to reduce the speed of vehicle to the required safe limit. Aljawi et al. [6] experimentally studied the internal inversion of circular frustum under quasi-static loading. The effect of wall thickness, frustum angle and material's inversion has been studied through quasi-static and dynamic drop weight tests.

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In Morris et al. study [7], the lateral quasi-static pressure of nested systems with lateral normal and inclined bindings has been numerically and experimentally studied. The results of this study show that lateral normal and inclined bindings can help increased capacity of energy absorption of these systems. Mahdi et al. [8] performed a four-step program to improve absorbed energy in axial loading for energy absorbent structures made from composite folding tube. They studied the rupture behavior, the best locating position, material measurement and optimization of geometrical form of the cross section in these four steps. The experimental results showed strong potential benefits of optimization of material distribution.

Olabi et al. [9] studied the energy absorbents in form of tubes made from mild steel or aluminum. Moreover, they briefly referred to different kinds of frustum-shaped energy absorbents and other kinds of materials and energy absorbent structures such as composites and honeycombs. In their study, common deformation states at the time of lateral and axial compression that were in form of indentation and inversion were considered. The results of study showed that the energy absorption capacity of the lateral compressed tubes increases with another deformation state that requires formation of plastic tubes. Moris et al. [10] performed dynamic and quasi-static tests on the energy absorbents in form of nested circular tubes through numerical and experimental methods. Quasi-static test was performed in speed of 3–5 mm/m and dynamic test was performed in speed range of 5–7 m/s and their crippling behavior and energy absorbent capability were studied.

Olabi et al. [11,12] performed lateral arrangement compressive tests from concentric circular and square tubes made from mild steel (DIN 2393) in dynamic loading state. The experimental results have compared the folding behavior and their energy absorption with the results of simulation results with LS-Dyna. These results show that energy absorption in optimized arrangement of tubes is more than standard arrangement of tubes. Marzbanrad et al. [13] studied the energy absorption values of thin-wall tubes with various geometrical dimensions by finite element simulation. Energy absorption of tubes with square, circular and elliptical cross section made of aluminum and steel has been compared, the experimental results of force–displacement for square steel tubes showed good conformity with the simulation results.

Dehghanpour and Dehghanpour [14] studied the energy absorption of compound tubes under lateral and axial quasi-static loading. Two nested tubes with the same geometrical specifications and different loading conditions were exposed to uniform quasi-static loading and the absorbed energy in each state was studied through simulation in LS-Dyna software and experimental tests. The results of the study showed that in the similar mentioned condition, energy absorption of compound systems is more than sum of energy absorption of individual parts of the systems.

Mohammadi Pour et al. [15] performed numerical simulation of square thin-wall tubes under inclined loading. They performed a parametric study for investigation of the effect of loading angle, speed and mass of rammer and geometrical parameters of tube such as thickness, length and width under inclined collusion on the energy absorption of thin-wall tubes. They also studied the energy absorption method under axial and bending loading and through simulation by ABAQUS; 180 different states have been simulated. The results of simulation that are compared with experimental results in other studies indicate the possibility of control of energy absorption behavior of thin-wall tubes using geometrical parameters.

Jones [16] studied the energy absorption of structures and pieces under severe loading due to ram and other dynamic collisions. He studied the effect of stoke axial loading for thin-wall tubes with cross section made from various materials by LS-Dyna software and compared their energy absorption with experimental results. Alavi Nia et al. [17] studied the energy absorption capacity and crushing of cracked square and cylindrical thin-wall aluminum tubes on axial compression. Furthermore, they studied the effect of height, angle, place and status of cracks on mechanical behavior of tubes. The results of this study show the considerable effect of cracks on collapse processes and folding shapes. Mirzaei et al. [18] performed multipurpose optimization of cylindrical aluminum tubes under impact loading and proposed absorbed energy and special absorbed energy as objective criteria for performance when the maximum crushing load should not exceed the permitted limit. In this study, geometrical dimensions of tubes such as diameter, height and thickness were selected as research variables.

Alavi Nia and Farshad [19] experimentally studied the effect of section geometry (circle, hexagonal and square) on mechanical behavior of thin-wall sections with and without aluminum foam under the effect of quasi-static axial load. The results of their study showed that circle section has the highest average force and energy absorption and on the other hand, aluminum foam leads to increased energy absorption and mean force value. Alavi Nia et al. [20] studied the normal collapse of thin-wall structures in Euler buckling exposed to inclined loads. In this study, the effect of collapse initiators on the energy absorption specifications of square tubes under inclined quasi-static loads in experimental and numerical conditions has been investigated. Tarlochan and Ramesh [21] performed experimental study on the composite sandwich structures' to evaluate their response to quasi-static pressure. They studied crushing parameters, i.e. maximum force, energy absorption, average crushing force and crushing force efficiency of various kinds of composite sandwich structures in a series of axial pressure tests.

Ghamarian and Farsi [22] studied the collapse of cylindrical thin-wall structures with circular cap (compound thin-wall structures) under axial quasi-statistic loading through laboratorial and simulation method and investigated the effective factors on the collapse. The comparison of the laboratorial and simulation studies showed that the presented model is more appropriate for determining collapse repose and force–displacement curve and the amount of absorbed energy. Parsapour [23] studied the behavior of aluminum thin-wall tubes with multi-cell square section with the symmetric cells as the energy absorbent under quasi-static and dynamic loading. The studies have been carried out through experimental, numerical simulation with LS-Dyna and theory analysis. The theory related to multi-cell square energy absorbents was generalized to asymmetric cells. At the end, a multi-cell section was presented whose energy absorption value on unit of mass shows 227% increase compared to ordinary unicellular section.

Rajabi [24] studied the behavior of cylindrical and frustum thin-wall aluminum tubes in compound and individual forms under axial quasi-static loading experimentally and numerically. He used controller to control crushing and increase energy absorption. The simulations have been done through LS-Dyna and experimental tests have been done through Santam apparatus with loading speed of 5 mm/min. The experimental tests and numerical simulations showed that the most absorbed special energy in compound condition is related to the structure that is not connected from top and have controllers with eight blades. The connection of the top base of cylinder and frustum leads to reduction of initial maximum force compared to the combined un-connected state and at the end welding operation leads to decreased energy absorption. Farshad [25] studied the effect of section (circle, hexagonal and square) on mechanical behavior of thin-wall sections with and without metal foam under axial quasi-static loadings experimentally and numerically. The thin-walled tubes produced in workshop were exposed to axial quasi-static loading by Instron testing and the results were compared to the results of simulation by LS-Dyna that showed good correlation. Moreover, they showed that among the samples with