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Lateral Crushing of New Design Cross-Sections

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ABSTRACT

Energy can be absorbed through deformation of different shapes of structures plastically. In this work, new design of aluminum (6060-T6) that consist of outer octagon tube with different shapes of inner tubes were exposed to lateral quasi-static loading. The behavior of tested systems and amount of dissipated energy were conducted numerically by ABAQUS commercial code. Different inner tubes shapes were investigated to compare between systems. The results cleared that the triangular system was most efficient to absorb lateral energy and to use as super energy absorber design

KEYWORDS

Energy absorption, Aluminum, Finite Element, ABAQUS, different shapes tubes.

INTRODUCTION

Tubular structures are extensively used as energy absorption members in vehicles to prevent and decrease the undesirable effects of collisions towards the occupants. These members dissipate the collision energy through plastic deformation. These structures can be verity to metal, composite, and polyurethane foam metallic filler [1]. Thin walled tubes metallic structures are an example of energy absorption members due they are cheap, multipurpose, and effective [2]. Axial crushing behavior of metallic tubes has been studied extensively [3] as they have attractive capability of energy absorption compared with laterally loaded [4]. However, metallic structures under lateral compression outperformed structures crushed axially, i.e the crushing force has less fluctuation, in addition the long-crushed tubes exhibit stable global bending mode [5, 6]. Employing of different shapes of single tube loaded laterally have been intensively considered [3]. For example, circular shape with different material such GFRP, CFRP, aluminum [7, 8] and mild steel [6, 9] tubes were investigated under lateral crushing. Yonghao Luoa and Hualin Fan [10] investigated the lateral crushing of hierarchical quadrangular tube. They found increasing of anti-crushing ability due presence of vertical ribs in horizontal sandwich tube. TrongNhan Tran [5] investigated the rectangular and square thin-walled tube loaded laterally. He found the multi cell of square tube is more effective than multi cell of rectangle tube.

Numerous studies of different tubes have investigated the lateral crushing responses of metallic structures by virtue of constraints [11-14] it was found presence of external constraint is the best method to increase energy absorption. Due to limited of plastic hinges of single tube crushed laterally which mean limited amount of absorbed energy, the use of tubes with constraints as nested system was proposed to enhance the capability of absorbed energy of metallic structure [9, 15] . New design of octagonal tube filled with different shape metallic structure nested tube was presented in this paper to improve the capability of metallic tubes performance to absorb lateral crushing energy. In this work the octagonal tube with many types of metallic structure as nested systems have been performed numerically. These systems have been compressed between two rigid platens. The aim of this work is to study the effect of octagonal tube with and without different filling of metallic-structure shapes on energy absorption which obtained after crushing laterally.

MATERIAL PROPERTIES

The octagon and different shapes filling tubes were from AL6060-T6. Cross section of all used tubes with 70 mm length and 1.7 mm thickness to estimate the behavior of tube deformation under quasi-static lateral loading. Figure 1 illustrates the octagon tube and other different used shapes tubes with all details.

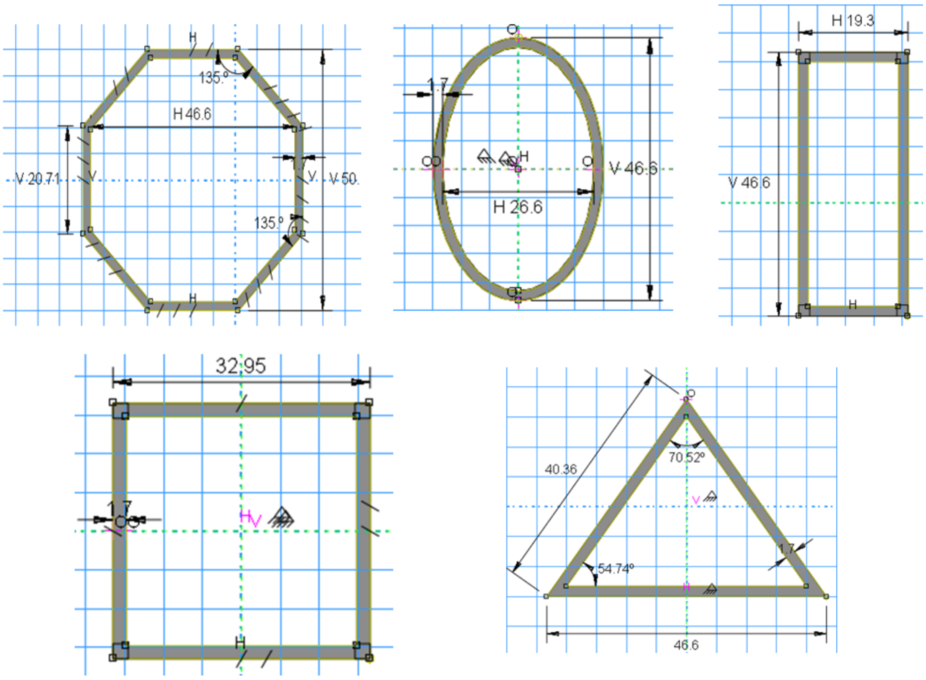

Figure 1. Front view of proposed used structures

The shapes in figure 1 (oval, rectangle, square and triangle) were used as core structure through cladding sacrificial body (octagon shape). These cores can be employed as energy dissipation structures. Increasing of plastic hinges due crushing sacrificial cladding that comprise different metallic tube shapes mean higher capacity of absorbed energy [16] as illustrated in Figure 2.

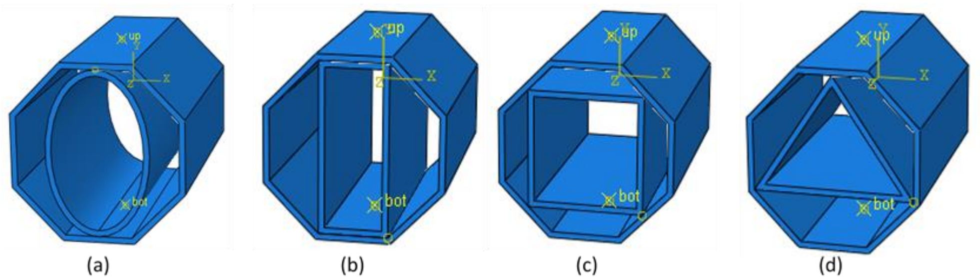

Figure 2. Illustrates different core structures a) oval, b) rectangle, c) square and d) triangle in octagon cladding

FINITE ELEMENT PROCEDURE AND VALIDATION

The finite element model was developed using the commercial ABAQUS/Standard Explicit to simulate numerically the lateral quasi-stating loading of tested models. All these models included large strain that led to change in volume that take place because of massive displacement. Skin and core structures were built using 3D solid element (C3D8R) which have large strain and large deformation[16, 17]. The two rigid jaws were modeled using four rigid elements (R3D4) [18]. The upper jaw allowed to move vertically in y-axis but fixed in x and z directions whilst the lower jaw was modeled to be fixed with all directions[15] to prevent rotation movements. General contact was conducted for all models in interaction module. The slipping between upper , lower jaws and outer skin tube (octagon tube) was prevented by tacking coefficient of friction 0.2 [6]. The mechanical properties of the sacrificial cladding and core tubes were made from aluminum alloy AL6060-T6 as shows in table 1.

Table 1. Mechanical properties of AL6060-T6[19]

Density (tone/m3)	Poisson's ratio	Yield stress (MPa)	Yield strength (MPa)
$2.7*10^{-9}$	0.33	71000	160

The validation of finite element has been conducted the comparison between experiment and simulation analysis [19]. The comparison explained good agreement of numerical with experimental results [19].

MODELING RESULTS AND DISCUSSION

Analysis of empty octagonal tube

Figure 3 illustrates the load- displacement relation of the empty octagon tube. It can be clearly seen the elastic region of the starting compression of the octagon tube is proportional linearly with displacement. At yield region the compression force increases progressively with increase of deformation. At plastic region the lateral compression load has been decreased due to the softening phase. This behavior is due reducing of the curvature radius at localized plastic hinges in the wall of tube during compression [13]. The compression lateral load climbs again due to total contact of the left lower sides of octagon tube with the lower platen at δ = 27mm and above figure 3 (a), till reach to the bigging of densification at δ = 31mm as depicted in figure 3 (b).

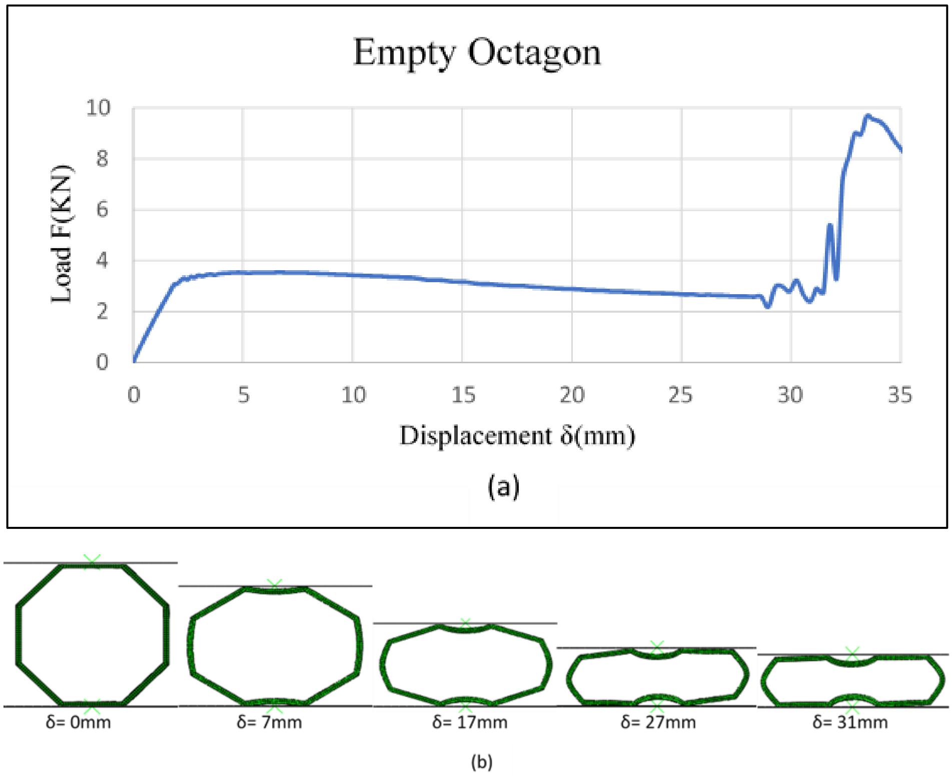

Figure 3. (a) lateral compression- lateral displacement curve, (b) steps of compression of empty octagon tube.

Analysis of ovel tube system

External octagon tube has been used to create oval system at fig. 4 (b). All events that have been done on the oval system are presented in fig. 4(a). This figure depicted identical response to the empty octagon but with an increase of collapse load level due presence of oval tube which expose more amount of material to plastic deformation. It can be clearly seen the decline of lateral compression load along lateral compression displacement due to the fact of the circular or semicircular have small collapse resistance to lateral compression. This decrease in lateral compression load continues till reach δ=31.7 mm as explained in fig 4 (a). At this phase the bending oval sides, be in total touch with octagon tube which raise the lateral load due form new plastic hinges [9] as illustrated in figure 4(a) and (b).

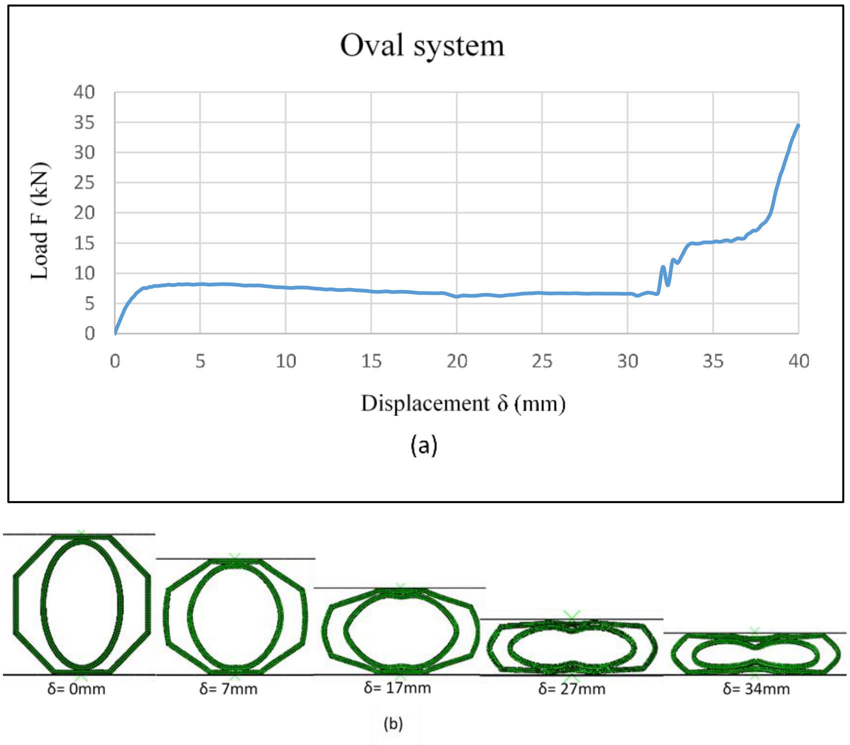

Figure 4. (a) lateral compression- lateral displacement curve, (b) steps of compression of oval system.

Analysis of rectangle tube system

The rectangular system consists of outer octagonal tube contain a rectangular tube. Figure 5 (a) shows the load-displacement history of rectangular system that illustrated in figure 5 (b). The collapse load level was increased due presence of rectangular tube. It can be noticed the compressive load decrease due to the softening of rectangular wall till δ=32mm. After that compressive displacement, compression of two contacted tubes increases collapse load level again due to the resistant to collapse which increase the amount of absorbed energy.

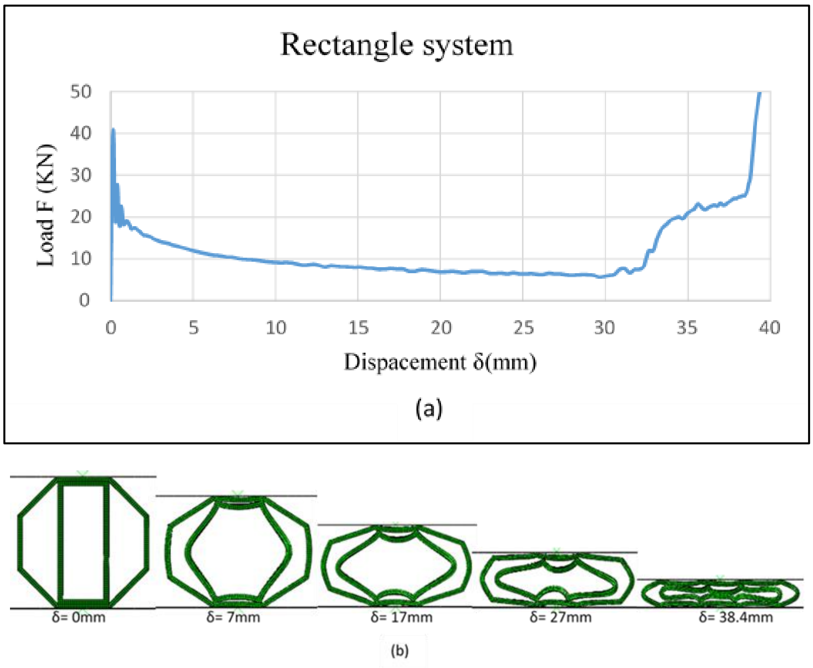

Figure 5. (a) lateral compression- lateral displacement curve, (b) steps of compression of rectangular system.

Analysis of square tube system

The responses of square system which composed of square tube inside octagon tube are presented in figure 6 (a). It can be clearly seen initial crushing of octagonal tube linearly followed by nonlinear increases of lateral load with increase of lateral compression. That fluctuant increment was due lateral collapse of octagon tube towards square tube which push by two lower angles to the octagonal tube as explained in figure 6 (b). At compressive displacement δ=14mm, the compressive load fiercely increases due to contact between outer and inner tubes which remains until reach δ=17mm. The lateral compression load return to decrease as a responsible of square wall to the compression which formed plastic hinge at each concavity. At displacement δ=30mm the compression load starts to rise again due the collapse resistance of whole system walls until the end of compression as in fig.6 (b).

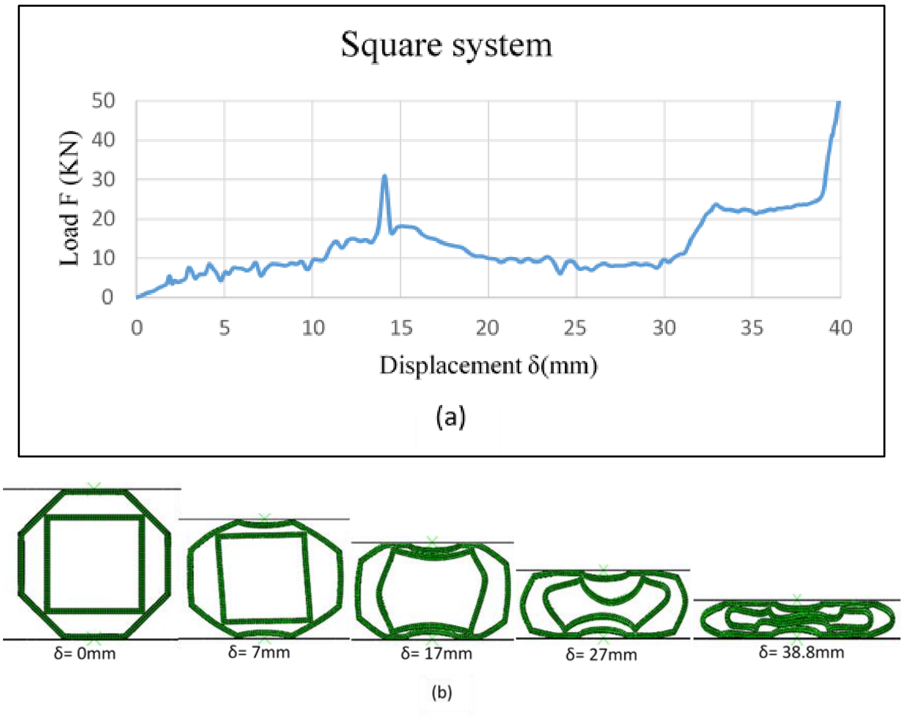

Figure 6. (a) lateral compression- lateral displacement curve, (b) steps of compression of square system.

Analysis of triangle tube system

Figure 7 presents the load-deflection responses of the triangle system. At elastic region the relationship of compression load increases linearly with increases of densification due buckling of octagonal tube only. At the beginning of plastic region, it observed the behavior of load-displacement is unstable due lateral load attempted to deform all the system [3]. This manner stays till reach to displacement δ=9.6mm which shows massive rise of lateral load because the triangle tube seeks to deform the octagon tube plastically through compaction to the bottom. After reaching to δ=17mm the lateral load increase and tip up the triangular tube inward which form additional plastic hinges as in fig. 7(b). Both of octagon and triangle tubes are deform, reason to rise the lateral load again as illustrated in fig. 7(a). The deformation mode of octagonal tube was changed due the triangular tube constrains the octagonal tube which mean large amount of deformation and high energy dissipation as in table 2. This behavior remains until reach to densification of the triangular system.

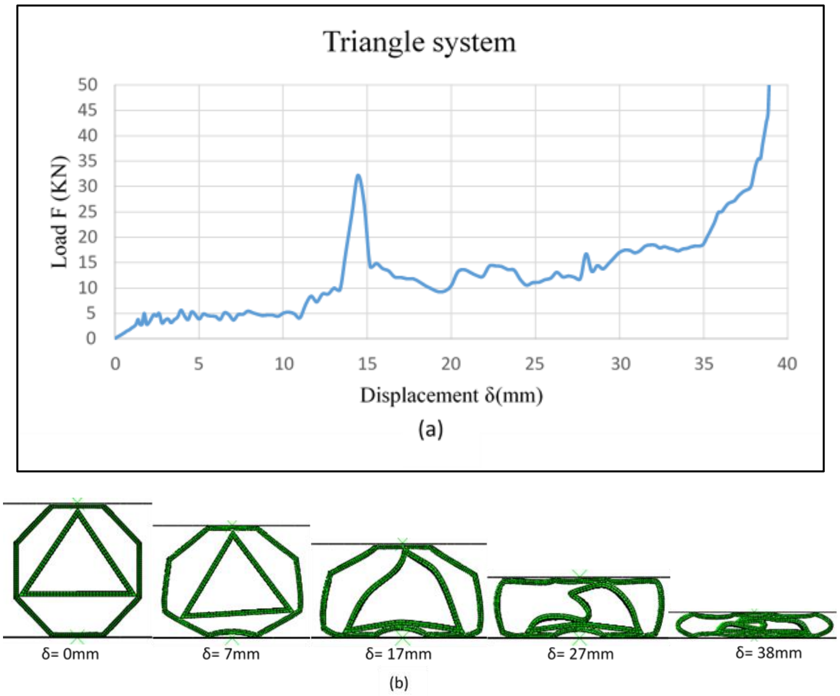

Figure 7. (a) lateral compression- lateral displacement curve, (b) steps of compression of triangle system.

Table 2. Presents the amount of absorbed energy for all used sysyems

	Empty octagon	Oval system	Reqtangle system	Sequare system	Triangle systam
Energy absorption KJ	164	364.5	482.7	514.2	583.2

CONCLUSION

In this paper, aluminum material was developed in new design of energy absober. Numerical simulation throuth ABAQUS software was conducted to examin responces of all studied systems under lateral quasi-static loading. The main results of this paper are summed up as following :

1. Defformation mode of the studied systems were depend on the type of the inner tube.
2. The absorbed energy was at the highest value when used triangular system.

Generally, using of an inner tube shape which early deform the outer tube leads to increase the absorbed energy.

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