Energy absorption capability of axial crushing of Hexagonal tube

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ABSTRACT

Tubular structures can dissipate kinetic energy of collision through plastic deformation. In this paper hexagonal aluminum (6060-T6) with variable tubes are proposed as energy absorption devices. The hexagonal tubes with and without trigger were compressed under axial quasi-static loading. The load-displacement indicators (peak load and energy absorption) of tested devices were investigated by Finite Element Analysis (FEA) through ABAQUS-DYNAMIC EXPLICIT. Different positions and numbers of triggers in columns used to compare between multiple columns. It was found that the hexagonal AL6060-T6 tube devices that have trigger particularly in the middle-offered significance enhancement to reduce peak load value. The results showed that the amount of absorbed energy from regular deformation tubes is proportional with increment of columns. Increasing of the tested geometrical, employing of trigger enhances the reduction of peak load and holds to design a superior energy absorption with controlled deformation modes.

KEYWORDS

Energy absorption, Aluminum, Finite Element, ABAQUS, hexagonal tube, trigger.

INTRODUCTION

Advances in technologies have led to high-speed transportation, some vehicles able to reach 300 miles per hour, but at the same time the probability of danger of life and accidents increases [1]. The number of road deaths in the world remains unacceptably high (the Global Road death rate is 18.2 per 100,000 population), with an estimated 1.35 million people dying each year [2]. So, the vehicle safety is gaining increasing importance for the Prevention of accidents, has proven to contribute to significant reductions in the number of deaths and serious injuries caused by road traffic accidents. All that was mentioned led to the increased interest to the automotive safety and crashworthiness. Therefore, the vehicle body must possess high performance in protecting occupants, i.e. high energy absorption capacity, and the main purpose of the crash absorber is to dissipate the impact energy in a very fine-tuned way such that the passenger cell brought to rest without much damage [3]. Most studies on tube sectional collapse have focused on dissipating kinetic energy in a controlled manner or at a predetermined rate [4].

Therefore, it attracted researchers towards specifically circular and square hollow tube structures [5], hexagonal [6] multi-cross-section [7, 8], frusta [9], resulting in intensive research into the structural response of pipes with different loading conditions [1]. On the other hand, some researchers paid attention to the type of metal and its ability to absorb energy, where some of them used mild steel [4, 10, 11] and others used aluminum alloys [1, 12-14], while some researchers relied in their research on composite materials [15-17]. Over time, aluminum alloys have become increasingly desirable for two reasons. Firstly, a convincing and very important factor is the light weight compared to conventional steel structures. Secondly, some aluminum alloys are good energy absorber members during collision. Therefore, today aluminum alloys are frequently found in bumper beams and crash boxes to absorb kinetic energy in accidental vehicle accidents [18]. In the current work axial crushing of hexagonal tube system has been carried out numerically. The hexagonal extruded aluminum tubes have been compressed between two flat platens. The aim is to study the effect of the number of hexagonal tubes and trigger on the energy absorption and peak load.

MATERIAL AND GEOMETRY
Hexagonal Aluminum tubes (AL6060-T6) cross section with varying number of tubes with 1.7 mm thickness and 150 mm length to predict the deformation mode of the tube that subjected under axial quasi static loading. Figure 1 presents the top view of typical hexagon with dimensions and the rest details.

![Hexagonal Tube Diagram](image)

**Figure 1.** Illustrate the top view with dimensions of hexagonal tube.

The deformation mode can be activated by using a geometrical trigger [19]. The trigger is used in an energy absorber structure which subjected to axil crushing. The trigger generates folding that decreasing peak load to avoid global bending [20]. The trigger applying in the present work was rectangle shape. There are two positions of the rectangular trigger were used in this work. The first position at the mid of two parallel walls of tube with length 5mm, width 12mm and 4mm on the both of sides of parallel walls. The second position with same dimensions at 4mm from the top and mirrored at the bottom of hexagonal tube. Figure 2. illustrates the hexagonal tube with and without trigger. The hexagonal tube profile for 12 specimens with length of 150 mm, wall thickness 1.7mm and its symbols are explained in the figure 2.

![Hexagonal Tube Profiles](image)

1C wo H  2C wo H  3C wo H  4C wo H

(a)
Figure 2. Illustrates the hexagonal tube a) without trigger b) middle trigger c) bottom and top trigger.

FINITE ELEMENT ANALYSIS PROCEDURE

The finite element method was used widely to predict and validate many experiments of structures as dynamic and static [21]. The commercial explicit dynamic code ABAQUS [22] version (6.14.1) has been employed to simulate numerically the deformation of hexagonal tube under axial quasi-static loading. The quasi-static procedure is not involved mass [23]. The full hexagon tube model was built as 3D to investigate a correct behavior of deformation of the tube. The 3D deformable structure consists of eight nodes solid elements (C3D8R) with large strain and deformation capability [24], while both of rigid platens are modeled by using four nodes rigid element (R3D4) [25]. The upper and lower rigid platens are confined the tube. The upper platen allowed to displaced in vertical y-axis direction whereas the lower platen was fixed [26]. Both of rigid platens were prevented from displacement and rotations excluding the displacement of the upper platen along vertical y-axis [27]. In all models the general contact was conducted in interaction property between components. To prevent sliding motion between both of upper, lower platens and both of ends of tube coefficient of friction was taken in consideration which is $= 0.2$. The mechanical properties of the tube that made of aluminum alloy AL6060-T6 with density $2.7*10^{-9}$ tone/m$^3$, Young’s modulus 71000 MPa, Poisson’s ratio 0.33, and the yield strength 160 MPa [28]. Because of using a complex section under quasi static axial loading, it is necessary to divide the hexagonal column into a number of parts which divides to essential structural elements [29]. Using of solid element to simulate extrusion aluminum tube and to obtain more realistic results. The deformation mode can be activated by using a geometrical trigger [30]. The trigger is used in an energy absorber structure which subjected to axil crushing. The trigger generates folding that decreasing peak load to avoid global bending [20].
NUMERICAL RESULTS AND DISCUSSION

Validation of finite element model

The validation of the numerical model is carried out by simulating dimensions and comparing against experimental data that obtained from analysis of square tube that subjected under quasi-static axial crushing as reported by [31]. Figure 3 Shows the famous relation of load versus displacement curve of experimental result of [31] and simulation results. It can be clearly seen the good agreement between experimental results that reported by [31] and numerical results.

![validation](image)

**Figure 3.** Shows the validation of numerical simulation

Effect of Number of Columns and triggers

Through the results shown in the tables (1) (2) (3) in general its obviously that the amount of absorbed energy increases with the increase in the number of columns in addition to the increase of the peak load as shown in figure 4 (a) (b) (c) (d). In the case of single column and two columns, the absorbed energy at its highest value when the trigger in the middle, and the peak load at its lowest value, as shown in figure 4 (a) and (b), respectively. Referring to the same tables (1) (2) (3) It can be clearly seen that the energy absorbed in the case of the three columns without trigger has the largest value reach to (8179 KJ), but by the highest peak load with the value (95 kN), the lowest value for the peak load is in the three columns containing trigger in the middle with a value of (74.5 kN). As for the lowest value of the absorbed energy, they were in columns with triggers at the top and bottom with a value reach to (7609 KJ).

Additionally, the energy absorption in the hexagonal tube slightly decreased after triggered compared to the tube without trigger as [32]. Due to the regular deformation in all specimens of the hexagonal tube (three columns), the values of the plastic folding exhibited a close result. In the case of the four columns, the largest value of the absorbed energy was in the columns without trigger with a value of (10988 KJ), but with the highest value of peak load which reach to (127 kN). As for the lowest peak load, it was in the four columns with trigger in the middle with a value (92). It is evident from what has been above-mentioned that the presence of triggers contributed to a significantly lowering the peak load and that the most appropriate or best place for the trigger is in the middle, no matter how many columns there are, This result shows the importance of the triggering mechanism in reducing the peak load value, where it work as initiator for folding and accelerate up the formation of the first fold. The technical of trigger has crucial effect on tested tube which contain corners in the geometry shape. It used to reduce the initial peak load to obtain a sooth fluctuational curve [33].

| Table 1. Explain the results of Energy absorption and Peak load for tube without trigger |
|-----------------------------------|---|---|---|---|
| Column’s number                  | 1C | 2C | 3C | 4C |
| Energy absorption KJ             | 2623 | 5112 | 8179 | 10988 |
Table 2. Explain the results of Energy absorption and Peak load for tube with middle trigger

<table>
<thead>
<tr>
<th>Column’s number</th>
<th>1C</th>
<th>2C</th>
<th>3C</th>
<th>4C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy absorption KJ</td>
<td>2811</td>
<td>5182</td>
<td>7677</td>
<td>10503</td>
</tr>
<tr>
<td>Peak load kN</td>
<td>29.5</td>
<td>57</td>
<td>74.5</td>
<td>92</td>
</tr>
</tbody>
</table>

Table 3. Explain the results of Energy absorption and Peak load for tube with multi triggers

<table>
<thead>
<tr>
<th>Column’s number</th>
<th>1C</th>
<th>2C</th>
<th>3C</th>
<th>4C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy absorption KJ</td>
<td>2633</td>
<td>4810</td>
<td>7609</td>
<td>10311.8</td>
</tr>
<tr>
<td>Peak load kN</td>
<td>30.6</td>
<td>57.5</td>
<td>74.7</td>
<td>94</td>
</tr>
</tbody>
</table>
The Deformation Mode

The deformation for all samples without trigger was regular. The type of mode of deformation for one column was mixed mode while the deformation of the rest specimens was concertina mode as in figure 5 (a). The first fold started from the top for all specimens. On one hand, in the case of one and two column the fold formed in touch with the moving upper platen. On the other hand, in case of three columns specimen the fold started after 5mm from the top, while formed after 10mm from the top of the four columns specimen. It can be clearly seen in figure 5 (b) the deformation of middle triggered columns is symmetric for all specimens [17]. The type of mode of deformation for all middle-triggered specimens is similar to the without trigger samples due to increase the number of columns which rise the crushing resistance. The first fold started at the trigger position for all specimens that have trigger in the middle due to the trigger accelerates fold forming. For the multi trigger (top and bottom trigger) columns the folds formed at the place of top trigger for one and multiple columns as in figure 5 (c). The type of mode of deformation for one and four columns was mixed mode while for double and triple columns was concertina mode.

Figure 5. Illustrates the deformation mode for (a) without trigger (b) middle trigger (c) bottom and top trigger.
CONCLUSION

This work presents the effect of number of columns and trigger position on energy absorption and peak load of hexagonal tube with and without trigger have been investigated numerically, under quasi-static axial crushing force. Based upon the results can be made the following summaries:

1. The best position of trigger to decrease the peak load in all number of tubes when the trigger in the middle of tube.
2. The deformation in all cases of hexagonal tubes were regularly.
3. The value of energy absorption increases when the number of column increase.
4. The value of peak load increase when the number of column increase.
5. The value of peak load decrease (in same number of column) when trigger mechanism used.
6. Catastrophic failure mode is not found in all cases deformation, although there is a critical condition, which is the three columns with triggers at the top and bottom.

REFERENCES


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