A Review on Performance of Thin-Walled Metallic Tubes as Energy Absorbing Structures

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Energy-absorbing structures made from thin-walled metallic tubes are lighter in weight, fuel-efficient and environmentally friendly. Despite these advantages, several other issues should be taken into account to provide better energy absorption capacity and increased crashworthiness. A better knowledge of selecting proper material and geometrical design can provide the occupants with better safety and lesser fuel consumption. This study presents a review of recent advances of thin-walled metal tubes with different configurations. Under static and dynamic loading conditions, a detailed explanation of the axial compression behaviour and energy absorption of thin-walled tubular structures is focused in this study. Many researchers have suggested that with the use of such energy-absorbing devices, structural deformations are ensured to minimize the damage to the main structural frame of automobiles.

Keywords: Crashworthiness, Energy Absorption, Tubular Structures, Bitubular Cross Section, Multi Cellular Tube.

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1 Introduction

In recent years there have been several types of research and experiments to make a light, safe and energy-absorbing structure in the field of transportation. It is required to complete the structure cost-efficient, environment friendly, and fuel-efficient. Moreover, apart from these qualities, we must ensure that the structure is safe for the passengers. An increase in the number of accidents and casualties, especially on the road, has led the interest of several researchers to study the structure and make the structure more energy absorbing by using thin-walled metallic tubes. The crashworthiness of an automobile structure can be increased by increasing the energy absorption capacity of that structure. Crashworthiness may defined as the minimum damage to the occupant and the structural frame. It should be ensured that the kinetic energy imparted to the structure during the collision is converted into another form of energy. This energy conversion is essential for the automobile structural frame and the occupants. Apart from the energy-absorbing capacity, the structure must be lightweight also. The lightness of a structure will directly define the fuel consuming capacity. By lightening the structure, the fuel consumption can be reduced thus the structure can be made environment friendly. Different experiments and numerical simulations have been done for the various advancements to the structural frame. From these researches, it has been observed that the thin-walled metallic tubes can be extensively used as energy absorbing devices. These metallic tubes are already in use in recent years to increase the crashworthiness performance of the automobile. Several researches have been conducted to see the performance of the thin-walled metallic tubes as energy-absorbing devices capable of converting kinetic energy into plastic deformation energy.

Recent advancements were also observed in the crashworthiness and energy absorption of regular thin-walled columns with a hexagonal cross-section [1]. Greater energy absorption and increased crashworthiness is observed when aluminium or polymeric foams are used as filler to reinforce the rectangular thin-walled tubes [2]. Whereas analysis also shows that the admirable crashworthiness is seen in empty aluminium foam filled with honeycomb-filled CFRP (Carbon Fiber Reinforced Plastics) tubes [3]. Other factors such as the angle of the inclination of the loading and the size of the projectile also plays a crucial role in deciding the energy absorption of a structural frame. The crushing behaviour under axial and oblique impacts can be improved for the bi-tubular conical circular cross sectioned structures [4]. The analysis of the crashworthiness and energy absorption of the several thin-walled metallic tubes is done, thus providing a better understanding of designing an efficient structure. The paper aims to provide comprehensive data from the various researchers by performing certain advancements to the thin metallic tubes.

2. Thin Walled Structures with Bitubular cross section

Bitubular structures are also better and more efficient energy absorbers during high impact crashes. Several researches show the comparison of such structures with other superficial structures. The crashworthiness of such cross-sectional structures has dramatically influenced. Many researchers whether the structure is bitubular in the form of a rectangular cross-section. The crashworthiness analysis of double section bitubular thin-walled structures is also done [5]. Under this study, stainless steel sheets specimens as shown in the figure 1 were used for the experimental analysis. The outer tube had circular cylindrical geometry. At the same time the triangular, square or hexagon polygon section were introduced to the inner tube. These specimens with polygon sections on the inner tube were tested for the quasi-static axial compression. During this test the effects after changing the diameter of these inner sections were observed. ASTM A24 TYPE 304 Stainless Steel sheet was used to prepare these specimens. The specimens were made from 0.478 mm thick sheet. This study suggested that the bi-tubular sections exhibit greater average crush force than the single tubular structures. For the case of inner inscribed polygons, as the diameter of the section increases, the total energy absorption also increased. Furthermore, when observed deeply, it was found that the inscribed polygon having hexagonal geometry have greater specific energy absorption (SEA) than any other inscriptions.

Fig. 1. Bitubular specimens with inner inscribed sections [5].

A research on bi-tubular conical–circular structure under oblique and axial impacts to improve the crashworthiness was done [4]. LS DYNA software was used to demonstrate these behaviours. The behaviour of double-walled structure with the outer plate as circular and the inner plate as frustum shaped was also observed. This structure is incorporated with or without foam filler. The aluminium closed foam filler was modelled with the help of Deshpande–Fleck material. This material have a specific characteristics due to which it is capable of simulating the fracture. Firstly the axial loading was done in bi-tubular structure without foam filler and secondly with foam filler. Under oblique loading, it was observed that the energy absorption and crashworthiness of bi-tubular structures is increased as compared to single tubular structures. But it is also found that the specific energy absorption is decreased and the initial peak load is found higher for foam filled structures. Therefore foam filled structures cannot be always trusted blindly. The research found that crashworthiness can be controlled and initial peak load can be decreased by using the newly prepared double wall structures. Under axial loading the energy absorption capacity of the combined bitubular tubes can be controlled [6]. The study was done both numerically and experimentally. The specimens used for the experimental tests were made up of aluminium. While during the crushing, the specimens were crushed with a loading speed of 10mm/min. This study provides a comprehensive comparison between the monotubular structures having circular and square cross section when both were tested against axial crushing. The numerical simulations required for this study were done on LS-DYNA software. The conclusions of this study opened the gate for further advancements in this direction.

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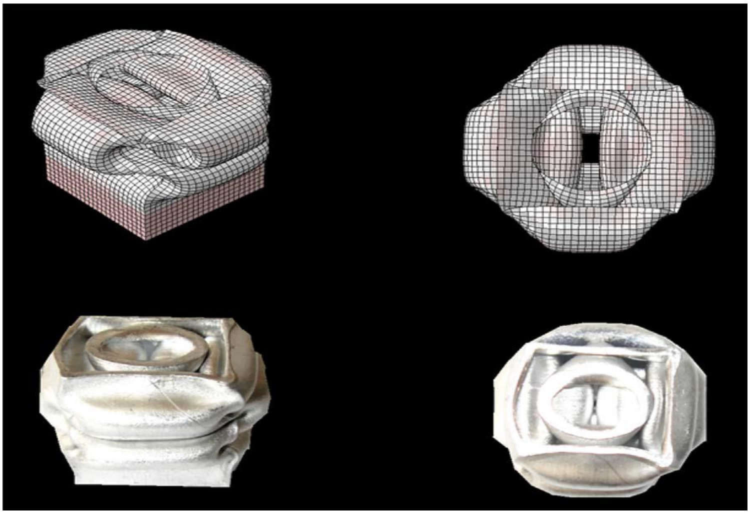

Fig. 2. Comparison of square sectioned bitubular tube and circular bitubular tubes [6].

The results showed that the specimens having circular outer cross sectional area possess greater energy absorption capacity and thus leads to an efficient crashworthiness. On the other hand, as depicted in the figure 2, the bitubular structures show the collapse mode as non-synthesis diamond collapse as compared to the global buckling behaviours of monotube circular tubes [6]. Apart from these factors, the most exciting result was that the specific energy of circular tubes is greater than the square cross sectioned tubes. Energy absorption capacity is increased if the end-cap is introduced in the tubular design during the deformation. Whereas it is also seen that this increase is higher in a circular tube.

3. Thin walled multi cellular structures

Multi Cellular tubes show the direct increase in the energy absorbing capacity and the crashworthiness. . As we increase the no. of cells, the effective energy absorption also tends to increase. Hence, these can also be seen as an effective alternative to the traditionally used tubes. Under axial loading conditions, some admirable results were seen for the crashworthiness of the thin walled structures which constituted of the multi cell profiles [7]. Polynomial Response Surface Method (PRSM) is used for the response surface module of the different structures. With the use of the models, parameter such as peak crushing force, specific energy absorption and mean crushing force were analysed after changing the length of side, thickness of the walls and introducing more cells. As per the experiment performed, square structures under axial loading result in more folds as the radius decreases. Figure 3 demonstrates the final deformed shapes of the models taken for the study [7]. It was observed and seen that the square tube should have a more increased wall thickness, more significant side length, and a larger no. of cells for the higher energy absorption. The higher the thickness of wall more will be the mean crushing force but it is inversely proportional to the side length of the tube. This Mean Crushing Force is also greater or more for the tubes, which have higher no. of the cells as compared to their counterparts.

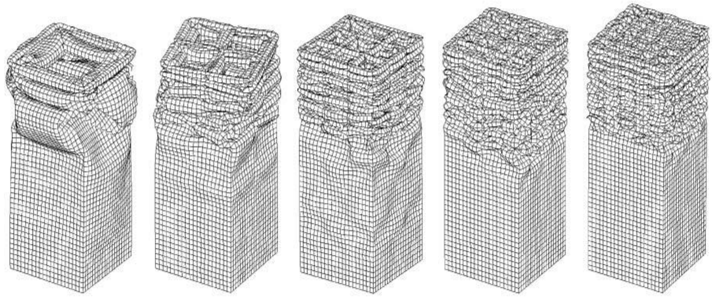

Fig. 3. Final deformed shapes: (a) single-cell structure, (b) two-cell structure, (c) three-cell structure, (d) four-cell structure and (e) five-cell structure [7]

The damage evolution criteria also shows effects on the energy absorption and crashworthiness of concentric and multi-cellular structures [10]. The study was conducted to investigate the behaviour of the multicellular tubes. Numerical simulations for this study were also conducted on the Abaqus. Several loadings were performed on the tubular structures having square, rectangular, triangular, pentagonal, hexagonal and circular cross-sections. This study constituted of two parts, for the tubes having concentric arrangement and the tubes having multi cell arrangement. The structures and specimens used in the study were prepared using EN AW-7108 T6 aluminium alloy. The study results revealed and opened a further source for the studies. The results showed that the crashworthiness performance of the concentric tubes is increased if the no. of edges are increased in the tube. Among all the multicellular tubes the tube having circular cross section showed the best energy absorption capacity. Hence the study concluded that the multi cellular tubes having circular cross section can be considered as the good energy absorbers and an effective as well as pocket friendly alternative. Under Dynamic loading conditions the multi-cell conical structures are optimized objectively [14].

The study was mainly oriented towards the crashworthiness performance of the multi-cell conical tubes having different geometrical cross sections such as octagonal, square, hexagonal, decagon and circular. Mainly two factors named as Peak Collapse Force (PCF) and Energy Absorption (EA) were taken in account under the Complex proportional assessment (COPRAS) method to analyse these tubes. Numerical Simulations of the test were carried under the LS-DYNA software whereas Artificial Neural Network (ANN) was combined with the Genetic Algorithm (GA) to optimize the geometry of these multi-cellular conical tubes. All the experimental analysis was performed on the Universal Testing Machine (UTM). The analysis and the results of this study reflected light on some of the interesting factors. It was seen that lesser is the PCF value of the tubes greater will be its crashworthiness capacity. If we gradually increase the cross sectional area of the tubes, the peak force decrease, hence it is a very good advantage of these multi cellular conical tubes as it can reduce the severe fatality to the passengers traveling in such type of the structural frame. In comparison of these multi cellular conical tubes it was observed that the tube having decagonal cross section is the best energy absorber while the tube having hexagonal cross section shows the worst energy absorption. The crushing analysis of the multi-cell triangular tubes under multiple impact loading cases was also inspected [20]. The study was conducted using the results obtained from the theoretical and numerical simulations on these multi-cell triangular tubes. The specimens of multicellular tubes of triangular cross section used for the experimental study were prepared by using aluminium alloy AA6060T4. The tube sections in the experiment are modelled with the Belytschko-Tsay 4-noded shell elements. Numerical simulations were done to find out the behaviour of these triangular tubes under the influence of load angle. As it is well known to us that a multi cellular tube will become short when deformed along its length during axial compression. The results and conclusions obtained from the study showed that a correlation between cross section of the tube and crush responses was seen after the numerical analysis. Apart from this relation, the efficiency of the Specific Energy Absorption was affected with the no. of cells. Whereas, Specific energy absorption and mean crush force) are rapidly decreased in comparison to the axial load.

4. Conclusions

After reviewing a large number of research papers it can be concluded that several new advancements in the structural design of metal tubes can lead to effective and increased crashworthiness. After going through various advancements, it is clear that the structures can also be made economical by keeping certain things in mind. Similarly in the case of bitubular structures, if the outer cross section of the tube is circular it leads to great energy absorption. In other ways, specific energy absorption of such tubes is greater than the traditional tubes. On the other hand if the diameter of the inner inscribed polygon of such bitubular structures is increased, it directly increases the specific energy absorption and the crashworthiness performance.

In the case of multi cellular tubes, the energy absorption is increased if the no. of cells is also increased but it is affected negatively with the side length of tube. Thus the side length of the multi cellular tubes should be reduced if the no. of cells of the tubular structure were increased and it leads to great crashworthiness performance. The effectiveness of the tapered multi cellular tubes can be increased significantly by introducing greater taper angles.

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