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A Review on Energy Absorption of Multi Cell Thin Walled Structure

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Abstract – *This paper reviewed the application of multi- cell thin walled tube in crashworthiness structure. The energy absorption performance of multi-cell thin walled has been reported to perform better compare to single thin walled structure. This paper also emphasis on the effect of difference geometry and shape toward energy absorption performance.*

Keywords: multi-cell thin walled, crashworthiness, energy absorption

1.0 INTRODUCTION

As a typical class of energy absorbers, thin-walled structures have been widely used in crashworthiness applications such as automotive industry to protect passengers from severe injuries. Thin-walled structures are widely used as kinetic energy absorbers for their cheapness, high energy absorption performance and weight efficient [1-4]. They can dissipate a large amount of kinetic energy through plastic deformation and fracture in case of collision. As tubes crushed longitudinally with progress collapse is high in energy absorption, a lot of researches have been carried out. The specific energy absorption (SEA, energy absorption per unit mass of material) is therefore the most extensively adopted index to evaluate the efficiency of energy absorption devices although other indices proposed by researchers are also important and useful. Since 1980s, filling the structures with cellular materials including foams and honeycombs has attracted wide research interests in the scientific community as an important approach to increase the SEA value of thin-walled energy absorber [5-9].

Over the past decades, substantial efforts have been devoted to investigation into the crushing behaviours of the thin-walled structures through analytical and experimental methods. For example, Alexander first derived an analytical solution to calculate the axial mean crushing force for circular tubes [10]. Wierzbicki [11] and Abramowicz [12] proposed the close form formulas to predict the axial crush response of aluminium thin walled tubes. The analytical predictions were validated experimentally by Abramowicz [13] and Jones, and Langseth and Hopperstad [14]. To achieve a lightweight design, multi cell configuration of thin-wall structures has exhibited superior capacity of energy absorption with proper weight efficiency. Comprehensive studies have been conducted theoretically, numerically and experimentally to investigate the crushing behaviour of the multi cell structures [15, 16].

The combination of analytical and experimental investigations into multi-cell structures has been recently gaining comprehensive attention. Krolak et al explored experimentally the stability and load-bearing capacity of multi-cell tubes. Their experiments showed that the multi-cell tube with a sectional area approximately 15% smaller than that of single-cell column has seven times higher buckling stress and 1.9 times bigger load bearing capacity. Meanwhile, Zhang et al [17], studied experimentally, analytically and numerically the deformation behaviour and energy absorption characteristics of circular multi-cell tubes with double, triple and quadruple cells. In their analytical models, a constituent element method was proposed and employed to predict the mean crushing force of the circular multi-cell tubes. In addition, Zhang et al,conducted the experimental investigations and theoretical analyses of multi-cell square tubes with different sections. Hong et al [18]. Proposed multi-cell tubes with triangular and Kagome lattices, and carried out quasi-static axial compression tests to reveal the progressive collapse mode and folding mechanism of multi-cell lattice tubes. It is noted that the above experiments largely focused on the crushing behaviour of multi-cell tubes under quasi-static axial compression.

Previous studies have primarily concentrated on the thin walled structures under axial loading and it is widely used as an energy absorption structure due to the fact that axial crushing of tubes have comparatively high energy absorbing capacity [10, 12, 19, 20]. However, according to A. Baroutaji [21] these structures have certain drawbacks such as the very large fluctuations of the collapse load about a mean load and the unstable deformation mode.

Furthermore, the deformation and energy absorption of multi-cell thin walled structure results are diverse according to various shape. Based on research done by A. Alavi Nia [22], a simple and multi-cell thin-walled tubes made from aluminium with triangular, square, hexagonal and octagonal sections were subjected to quasi-static loading. The results showed that the energy absorption capacity of multi-cell sections is greater than for that of simple sections .Also, hexagonal and octagonal sections in a multi-cell configuration absorbed the greatest amounts of energy per unit of mass.

1.1 General characteristic for energy absorption structure

The energy-absorbing structures have to sustain intense impact loads, so that their deformation and failure involve large geometry changes, strain hardening effects, strain-rate effects and various interactions between different deformation modes such as bending and stretching. For these reasons, most energy-absorbers are made of ductile materials. Low carbon steel and aluminium alloys are the most widely used [14, 23], whilst non-metallic materials such as fibre-reinforced plastics and polymer foams are also common especially when the weight is critical. These are some fundamental principles and guidelines for all energy absorption general applications [19, 24, 25].

I. Irreversible energy conversion

The energy conversion by the structures or materials should be irreversible, because of the structures or materials should be able to convert most of the input kinetic energy into inelastic energy by plastic deformation or other dissipation processes, rather than storing it elastically.

II. Restricted and constant reactive force

The peak reaction force of an energy absorber should be kept below a threshold and ideally the reaction force should remain constant during the large deformation process of the energy absorbing structure.

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III. Light weight and high specific energy-absorption capacity

The energy-absorbing component should be light weight itself, so that it will increasing the specific energy-absorption capacity (energy-absorption capacity per unit weight), which is of vital importance for vehicle-carried energy absorbers (especially for aircraft) and personal safety devices.

IV. Low cost and easy installation

The manufacture, installation and maintenance of such energy-absorption devices should be easy and cost-effective.

1.2 Fundamental of energy absorption

Generally, energy absorption (EA), specific energy absorption (SEA), mean crushing force (MCF), the peak force (PCF) (Fig. 1), the crash load efficiency (CLE) are extensively used to measure the crashworthiness characteristics of thin-walled structures. Taking the axial impact as an example, the energy absorption of a structure is determined by integrating the crashing force with respect to displacement x as:

$$E(d) = \int_0^d F(x)dx$$

Where d denotes deformation distance and F is the axial impact force. A typical axial crushing force–deformation curve of a thin-walled structure is illustrated in Fig. 1. The mean crushing force (MCF) for a given deformation can be calculated as:

$$MCF(d) = \frac{Ed}{(d)}$$

The specific energy absorption (SEA) is considered a more critical criterion to measure energy absorption capability of unit material, defined as the ratio of absorbed energy to the structural mass M

$$SEA = \frac{E_{total}}{m}$$

Obviously, a higher SEA value indicates higher capacity of energy absorption. The crash load efficiency (CLE) can be calculated as the ratio of the mean crushing force MCF to the peak crushing force PCF as shown.

$$CLE = \frac{MCF}{PCF}$$

As an energy absorber, the highest CLE is preferred.

2.0 COMPARISON OF ENERGY ABSORPTION BETWEEN VARIOUS SECTION SHAPES

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There have been several studies in the literature reporting on the considerable effect of energy absorption between various section shapes.

Ali Alavi Nia [22, 26] was conducted a research to identified the energy absorption performance and deformation of thin walled tube with various section shapes (circular, square, rectangular, hexagonal, triangular, pyramidal and conical) by numerical and experimental. Each tubes have the same volume, height, average section area, thickness and material and are subjected under axial quasi static loading. The result of experimental and numerical show that section shapes have considerable effect on the energy absorption capacity. The circular shape have the height total energy absorption capacity and mean force compared to other shapes.

Another research from Ali Alavia Nia and M. Parsapour [27] conducted to investigate the energy absorber in the form of thin walled tube with various section shape (triangular, square, hexagonal and octagonal sections) are experimentally and numerically studied. The specimens were made from 0.1mm thin aluminium sheets (foil). The sheet edges were connected using liquid adhesive during the fabrication process. Simulations were done using LS- DYNA code to identify the energy absorption and load-displacement curve of thin walled structure under quasi-static axial loading. The result shows that the octagonal have the most energy absorption followed by hexagonal, square and triangle respectively. Meanwhile, both of researcher also investigate the effect of multi-cell thin walled structure to identify the effect of adding the cell on the same shape.

3.0 THE EFFECT OF NUMBER OF CELLS IN MULTI-CELL THIN WALLED STRUCTURE TOWARD ENERGY ABSORPTION

Since 1980s, filling the structures with cellular materials including foams and honeycombs has attracted wide research interests in the scientific community as an important approach to increase the specific energy absorption (SEA) value of thin-walled energy absorber. In the past decade, the employment of multi-cell sections was found to be an effective way to increase the energy absorption efficiency of thin-walled structures. Recently there are numerous experiments and numerical that have been done to investigate the performance of energy absorption of multi cell thin walled. Mostly the results shows that the multi-cell thin walled perform batter in terms of energy absorption compare to single thin walled [1, 6-8, 26-33].

According to research that have done by Xiong Zhang and Hui Zhang [17] find out that a multi-cell columns are highly efficient energy absorbing components. In their research, experimentally, numerically and theoretically have been studied to identify the energy absorption performance of multi-cell thin walled structure under axial crush. Circular multi-cell columns with different sections as shown in figure 1 (single, double, triple and quadruple cell sections) are axially compressed quasi-statically and numerical analyses are carried out by nonlinear finite element code LSDYNA to simulate the experiments. Deformation mode and energy absorption of multi cell thin walled structures were compared with simple thin walled structure and the result found that the energy absorption efficiency of multi-cell columns is significantly higher than that of simple circular tube.

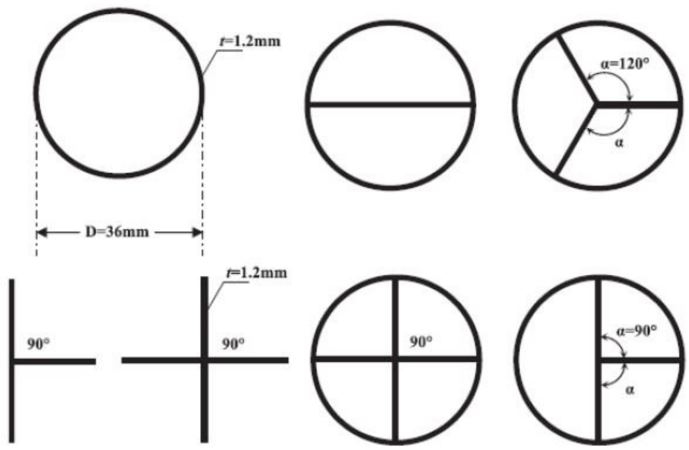

Figure 1: Cross section of circular multi-cell columns

Research finding by Zhiliang Tang [31] also points towards that multi-cell circular tube under axial loading perform better energy absorption capacities. The result found that when the number of cell of circular tube increasing the total energy absorption also increasing. This research also found that the wall thickness, and radial directions have a distinctive effect on energy absorption.

4.0 CONCLUSION

This paper presented an inclusive review on the energy absorption of multi cell thin walled structure in crashworthiness application. A vast number of available references shows that the multi cell thin walled perform better in terms of energy absorption compare with simple or single thin walled. However, multi cell are much heavier and not easy to manufacture hence these are some drawback of multi cell that will affect the amount of SEA. Other than that, the previous research also indicate the effect of width and thickness in energy absorption performance.

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