CRUSHING MODES OF ALUMINIUM TUBES UNDER AXIAL COMPRESSION USING FINITE ELEMENT ANALYSIS

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ABSTRACT: Nowadays, aluminium tubes have been used widely as a controlled absorption of kinetic crash energy. The energy absorption process is subjected to axial loading is based on the formation of plastic folds. A numerical study of the crushing of aluminium circular tubes has been carried out to investigate their buckling behaviors under axial compression and to predict the energy absorbed by the tube. Circular tube with diameter 25.4 mm, height 25.4 mm and thickness 0.29 mm is compressed axially with velocity 5 mm/min using ABAQUS/CAE 2016 between two rigid platen. Typical deformation mode is studied and presented. Mixed mode has been deformed because of the ratio of the wall thickness, diameter and the length of the tubes. These approved that geometry of the tube influence the deformation mode as well as the energy absorbs by the tube.

KEYWORDS: *Finite Element Simulation; Circular Tube; Deformation Mode; Mixed Modes; Energy Absorption*

1.0 INTRODUCTION

Aluminium has been used widely in the collision kinetic energy dissipation system of ships, motor vehicles, aerospace and many other fields because of high strength-to-weight ratio, high energy absorbing efficiency and low cost, thin metal tube structure [1]. Over the past year, studies have been conducted on the crushing of thin-walled circular tubes since they offer better energy absorption capability [2-4]. The axial crushing of thin-walled tubes constitutes a very effective means of absorbing energy.

The function of an energy absorber is to absorb kinetic energy upon impact and dissipate it in some other form of energy, ideally in an irreversible manner. Non-recoverable (inelastic) energy can exist in various forms such as plastic deformation, viscous energy and friction or fracture energy. Circular and square sectioned tubes are one of the most commonly used structural elements due to their prevalent occurrence and easy manufacturability.

The application of thin-walled tubes in energy absorption systems under impact loading has attracted a considerable amount of attention [5-6].

Many researchers have used the finite element method to study the energy absorption characteristics of thin-walled metal [7-9]. Abramowitz and Jones [10] studied the transition from initial global bending to progressive buckling of tubes loaded statically and dynamically. Younes [11] studied the crushing behavior of thin tubes with various cross-sections, circle, ellipse, triangle, square, pentagon and hexagon when subjected to axial loading and found that the greatest energy absorption capacity was obtained by the circular cylinder while the square tube absorbed minimum energy. Energy absorption of metallic shells is studied by Marsolek and Reimerdes [12]. They investigated the influence of different induced folding modes in order to optimize the energy absorption behavior axially loaded metallic cylindrical shell structures. While Velmurugan and Gupta [13] studied a comparison between metallic and composite shells based on the deformation and energy absorption characteristics.

The quasi-static collapse of axially compressed ductile tubes indicates the influence of tube length on collapse mode. A classification chart has been drawn by Andrews et al. [14].

There are tremendous of works have been done to improve energy absorbers criteria. Hosseinipour and Daneshi [15] introduced grooves in the tubes to force the plastic deformation to occur at predetermined intervals along the tube. The aims are to control the buckling mode and predicting energy absorption capacity of the tubes. Salehghaffari et al. [16] attempts to improve energy absorption characteristics of circular metal tubes by press fitted a rigid steel ring on top of circular aluminium tubes. The rigid is driven into the cylindrical tube and expands the top area, then the plastic folds start shaping along the rest of the tube length as the compression of the structure continues.

Alexander [17] was first to provide a theoretical model for axial crushing of a circular tube for the ring mode. The model is shown in Figure 2. During formation of a single fold, there circumferential plastic hinges occur. Assuming that the fold goes completely outwards, all the material between the hinges experiences circumferential tensile strain. The external work done is dissipated by plastic bending of the three hinges and circumferential stretching of the materials in between. The analysis complete for axisymmetric collapse of circular tubes, developed by Alexander in 1960. Several modifications have been done by Johnson [18], Abramowicz [19] and Abramowicz and Jones [20-21].

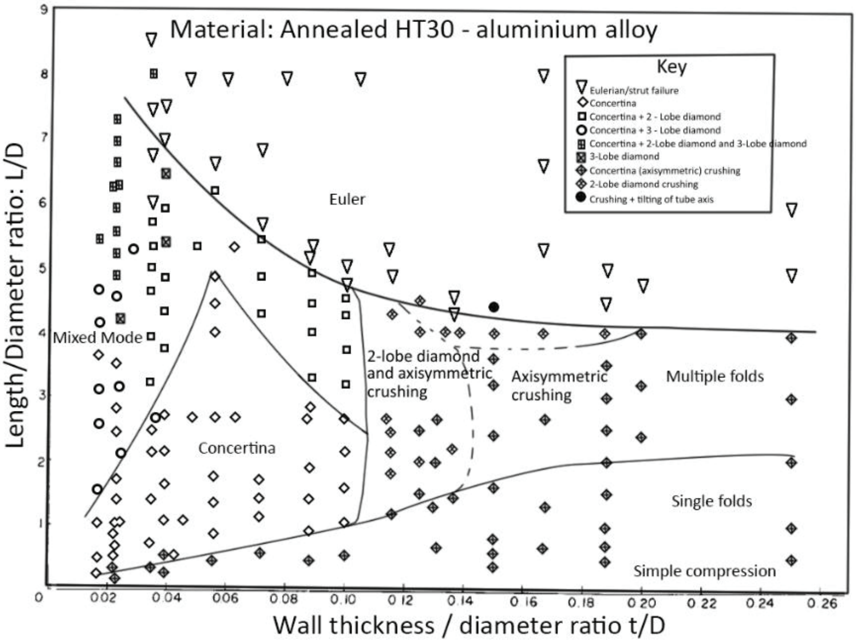


Figure 1: Classification of collapse modes of aluminium alloy tubes [14]

The aims of this study are to obtain the numerical data on the crushing of circular tube, to predict the absorbed energy and the buckling deformation of the aluminium tube due to geometric of tube; (i.e: wall thickness, length and diameter). The circular model crushed axially in quasi-static condition by using ABAQUS 2016. The energy absorbs and deformation mode was examined.

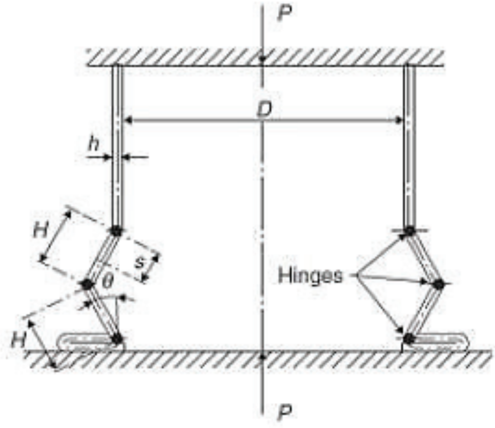


Figure 2: Simple theoretical model for axisymmetric collapse [17]

2.0 NUMERICAL MODELS

Finite Element models were developed using the commercial package ABAQUS 2016 to simulate the crushing of aluminium tubes. A typical Finite Element model consists of a cylinder clamped by two rigid compression plates. The axial compression is simulated by moving down the upper plate with velocity applied is 5mm/min, while the lower plate is stationary.

The properties of the material used in the simulation were provided from the actual material properties of aluminium alloy A6061. Its Young's Modulus,E and Poisson's ratio, v are 68.9 GPa and 0.33 respectively. The initial yield stress is 80 MPa. And ultimate tensile strength is 310 MPa. The density of aluminium tube is 2700 kg/m3. The outer diameter of the aluminium tube is 25.4 mm, height 25.4 mm and thickness 0.29 mm. Detailed description of the circular tube is illustrated in Figure 3.

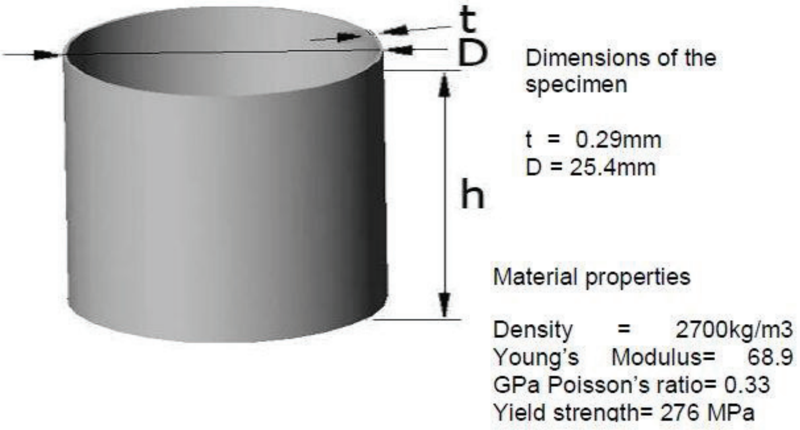


Figure 3: Parameter of circular tubes

The circular tube model used in the present finite element simulation was generated by using the element S4R. This element is a three-dimensional doubly curved four node shell element. Each node has three-displacement and three-rotation degrees of freedom. Moreover, this element is considered a general-purpose shell element where it allows for large strains as load increases. In order to predict the overall response accurately, the mesh of finite elements was fine and uniform with equal number of elements along the length of the tube and through its circumferential direction. The mesh size of the model is 5200 elements as shown in Figure 4.

On the other side, the circular tube model was crushed axially between upper and lower rigid parallel plates. These two parallel plates were simulated by using three-dimensional four-node rigid elements R3D4. The tube was crushed by pushing down the upper rigid plate. The latter was fixed in all degrees of freedom except the vertical downward displacement where the loading was applied. However, the lower rigid plate was stationary by constraining its whole degrees of freedom. The tube model rested free on the lower rigid plate however the applied force was attained as a reaction created from the pushing of the upper plate. The quasi-static loading condition was achieved by moving the upper plate slowly downward over a sufficiently long time.

It is noted that the tube was not completely free due to the effect of friction between the tube model and the crushing parallel plates.

General contact algorithm was used to simulate the contact interaction between the thin- walled tube and two platens. The contact properties were rough contact with an infinite coefficient of friction which are no slip occurs once points are in contact. The progressive deformation shape was continuously monitored for the tube and the corresponding force-axial displacement curve was depicted.

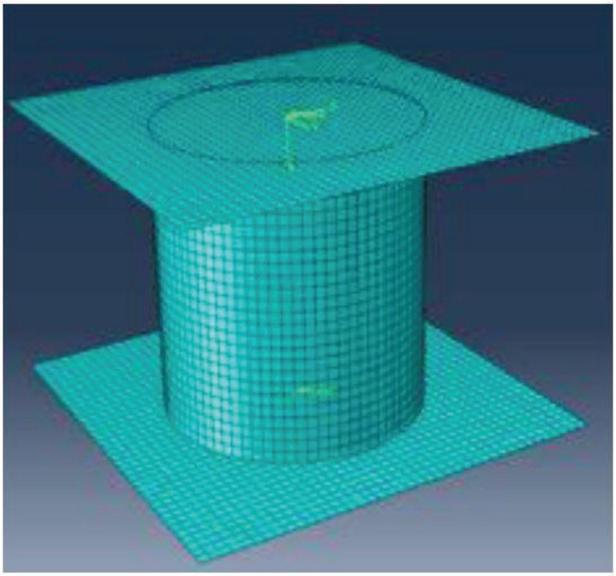


Figure 4: The mesh model of circular tube using ABAQUS 2016

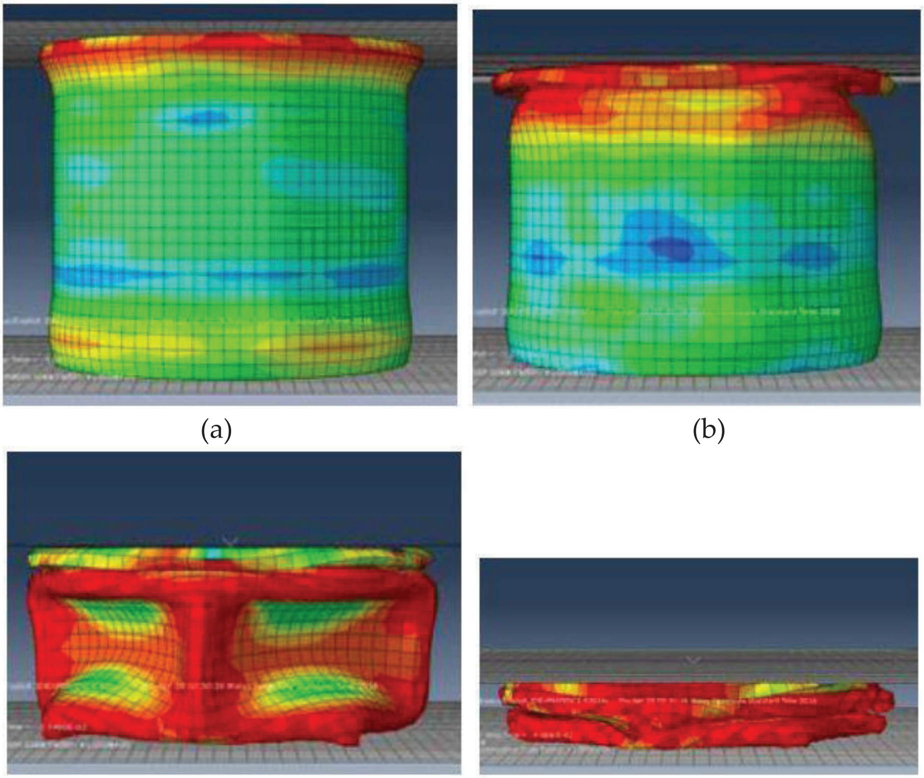
3.0 RESULTS AND DISCUSSION

3.1 Deformation Modes

The buckling mode of an empty tube strongly depends on the geometry of the structure. The energy absorption process of aluminium circular tube structures is based on the formation of plastic folds, which results in a characteristic force– displacement curve. The folding pattern of a circular tube is governed by the preceding buckling mode, which depends on the shell geometry and on the loading conditions.

Circular tube structures used for energy absorption mostly fail due to structural instability when subjected to axial loading. This instability is usually followed by a progressive folding progress. After the buckling load is exceed a geometric buckling patterns develops while the load which can be carried by the shell drops.

Influenced by the boundary conditions and imperfections, one buckle grows and a first plastic fold develops. Axially neighboring regions of the shell are pre-deformed and a relaxation of the remaining part of the shell can be observed. An axisymmetric mode was noticed during the deformation of the circular tube. The entire tube models initiated folding from the top end in contact with the movable upper plate.



(a) (b)

(c) (d)

Figure 5: Deformation modes of circular tube at (a) 20%, (b) 40%, (c) 60% and (d) 80% percent strains

Figure 5 shows the buckling behavior of the circular tube at various percentages of strains. At the beginning, this at 20% strains the tube deformed as a concertina mode. The shell element folds predict only 2 folds at 40% strains. After that, tube deformed as diamond mode at 60% strains. At 80%, the wall of tube continues collapsing until densification.

These phenomena is called mixed mode because the cylinder deformed both, concertina and diamond mode. In these simple circular tubes, the ratio of length to diameter (L/D) is 1 and ratio of wall thickness to diameter (t/D) is 0.0114. According to Andrews's classification [15], the above range is in mixed deformation modes. It is proven by using simulation analysis, the tube deformed as mixed mode.

3.2 Load Displacement Curves

Figure 6 shows the load-displacement curves. The absorbed energy was obtained by calculating the area under the load-displacement curve. Afterwards, the mean loading was calculated by dividing the absorbed energy by the total displacement.

When compression started, the first fold usually tended to form outwards from two opposite sides of the tubes and inwards from the other two sided. The folds started with a load peak rise rapidly higher than the other peaks, until the tube sides collapsed. The load then decreased rapidly to the first local minimum, in which the first outward and inward flattening folds were fully developed.

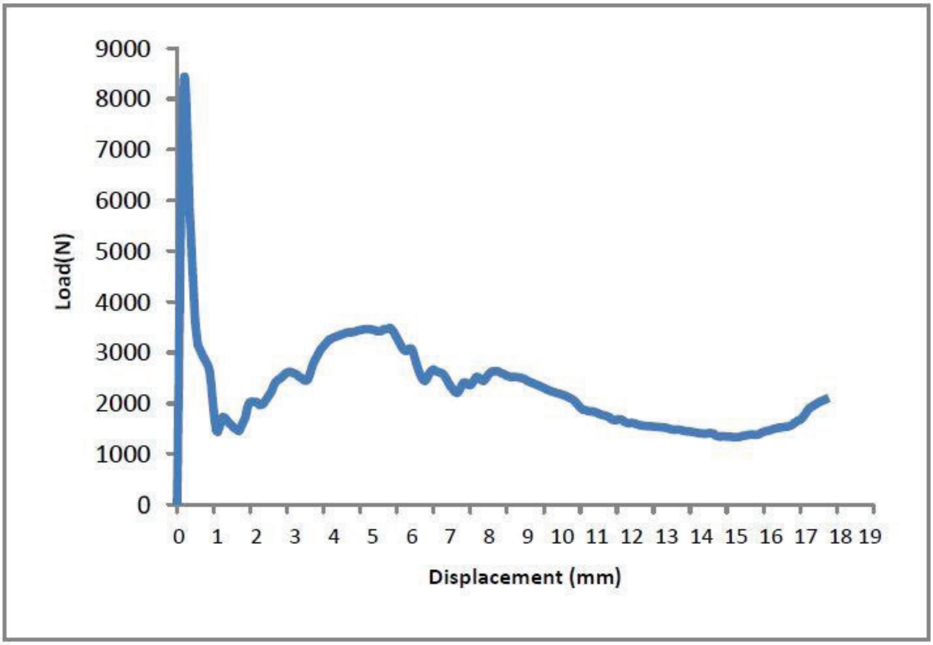


Figure 6: Load-displacement curves for circular tube

Then, the second drop of the load occurred again, indicating the second folding of the walls. Thus, the load dropped when new folding started and rose when the walls came in contact. This process repeated until the folding of the tubes was investigated in the impact loading.

The general load-displacement characteristics can be described by a rapid rise of the load initiated due to the elastic compression of the tubes. After that a rapid drop of the load was observed when one end of the tube started folding. Thereafter the load decreases to lower values and shows fluctuations as the empty tube progressively deforms in diamond mode until densification region.

Generally, there are many variables to analyzing energy behavior of a structure [22]. From the graph we can obtain the value of peak load is about 8500 N. Energy absorb by the tube is about 40.44 Nm and the mean load is 2300 N.

4.0 CONCLUSION

In this paper, axial crushing of aluminium circular tube was subjected to axial compression. Numerical simulations of the crushing tubes have been carried out with finite element analysis using ABAQUS 2016. Typical deformation mode was studied and presented. Because the tube is too thin, with respect of the ratio of the wall thickness, height and diameter it may have a strong tendency to undergo the diamond mode buckling, greatly reduce the energy absorption. Besides, the collapse mode is very dependent on impact velocity. The result shows that the aluminium circular tube absorbed energy about 40.44 Nm.

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