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Thin walled circular beams with sinusoidal embedded patterns under axial impacts

Zeeshan Qaiser [a,*], Omer Masood Qureshi [b], Shane Johnson [a], Abid Ali Khan [b]

[a] Center of Advanced Mechanics, Material and Structure (CAMMS), University of Michigan - Shanghai Jiao Tong University Joint Institute, 800 Dongchuan Road, Shanghai, China
[b] Automotive Design and Safety Lab, Institute of Space Technology, 1, Islamabad Highway, Pakistan

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ABSTRACT

Several recent developments have shown that introducing sinusoidal patterns on square section automotive crash absorber beams increased the energy absorption. This paper studies the behaviour of patterned circular tubes when used as crash absorbers. The effect of varying parameters of radial and longitudinal geometrical pattern frequency on internal energy absorption and energy absorption effectiveness factor is also studied in this work. Different types of patterns were simulated in axial impacts in which two geometrical pattern frequencies (radial and longitudinal) are multiplied. A numerical investigation was carried out using the commercially available LS-DYNA™ solver. The investigation was verified using existing analytical models. Results indicate that the circular sinusoidal patterned tubes behave better in energy absorption in axial impact. However, circular tubes have an altogether different collapse mode therefore the pattern formation has to be modified and optimized differently as compared to square beams. A new set of patterns named as CBC patterns is proposed in the study which increased the energy absorption of circular tubes significantly. An increase of about 36.86% in energy absorption is noted and energy absorbing efficiency factor is escalated from 2.23 to 3.05 in the best case. This research may further endorse the feasibility of using sinusoidal patterned tubes in mainstream engineering applications.

1. Introduction

An automotive crash absorber is a system used to convert kinetic energy into absorbed internal energy during a car accident. There are several types of collapsible impact energy absorbers used in industry. Aluminium thin walled tubes are commonly used structural members in the crumple zones. Thin walled tubes offer advantages like high stiffness, high strength to weight ratio and high impact energy dissipation.

There are different principal modes of collapse for thin walled tubes: axial crushing, bending, lateral flattening, lateral indentation, splitting and inversion. In real life automotive accidents, collapses are a combination of these modes. It is very important to study the performance of thin walled tubes in axial collapse as it is prime mode of collapse.

The behaviour of thin walled circular tubes under axial impact has been extensively researched. In one of the fundamental studies on the subject, Alexander [1] worked on a rigid plastic analysis and gave the expression for the mean crushing load of an extensible thin walled cylinder. Abramowicz and Jones [2] improved Alexander's model for average crushing load of thin walled cylinder for the concertina mode of deformation. Reid [3] performed experiments on axially compressed metal tubes and this validated the previous work by Abramowicz and Jones in which there was good agreement.

Pugsley et al. [4–5] studied the diamond collapse mode of thin walled cylindrical tubes and proposed a new model for the diamond mode of deformation which is based on row folding of a number of diamonds. A new model for calculation of average crush force was also proposed in the study. Jones [6] studied the quasi-static analysis and its transition to dynamic and global bending.

Many innovative solutions have also been proposed in literature in order to improve energy absorption capability of thin walled cylindrical crash absorbers. Reddy et al. [7–8] filled the circular tube with foam and wood and studied their behaviour under axial compression. Reid et al. [9–10] developed a structural plastic shock model for one dimensional ring systems and studied the performance of braced metal tubes. Carney III et al. [11] worked on stiffened metallic tubes and determined the

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[*] Corresponding author.
E-mail address: zeeshan@sjtu.edu.cn (Z. Qaiser).

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performance characteristics experimentally.

Many review papers are written on the structural collapse of crash absorbers. Johnson and Reid [12–13] compiled the principal modes of collapse of crash absorbers. Jones [14] compiled the plastic behaviour of structures; Alghamdi [15] reviewed the common shapes of collapsible energy absorbers and deformation of the most common modes.

Work has been done previously on adding patterns on square (box) and rectangular beams. The indication of patterns was first proposed by Zhang et al. [16] and they added triangular patterns on thin walled beams which enormously enhanced the energy absorption in axial collapse by changing the buckle formation mode. Sinusoidal patterns were first studied by Jiang et al. [17]; however, they created a surface by adding a sinusoidal perturbation which reduced the energy absorption slightly.

Qureshi and Bertocchi [18] numerically studied various types of bi-directional patterns on Aluminium box beam crash absorbers. They concluded that although most pattern types did not increase the energy absorbed, some patterns, in particular the SLD patterns were very efficient. Forty two percent increase in energy absorption was noted in their study from the best patterns. In their subsequent research [19] on patterns, they effectively formulated a triggering mechanism by morphing the pattern a little throughout the length of the beam. Qaiser et al. [20] studied the effect of adding SLD patterns developed by Qureshi and Bertocchi [19] on individual and combination of walls of box beam crash absorbers and effect of progressive triggers under deep bending collapse. Qureshi et al. [21] in his work studied two different types of triggering mechanisms in sinusoidal embedded patterned beams, i.e. conventional notched triggers and progressive frequency triggers under oblique impact. In his notable work, Jones [22] discussed an energy efficiency factor. This factor is dimensionless and it can be used to make comparisons of energy effectiveness of crash absorbers of various geometrical shapes and materials.

A new set of CBC patterns are developed in which two set of sinusoidal perturbations, i.e. radial and longitudinal, are formulated and added in the thin walled beams with circular cross-section to improve energy absorption under axial impacts.

Hydroforming techniques in engineering applications have made it possible to manufacture such patterned circular beams using a properly shaped die.

The aim of this research is to develop perturbation patterns for thin walled beams with circular cross sections which could control the collapse formation forming collapse wavelengths which enhance energy absorption characteristics. The collapse results obtained after incorporating sinusoidal perturbations are compared in terms of both energy absorption and energy absorption effectiveness factor (φ) devised by Jones [22].

2. Development of CBC patterns

Numerous types of geometrical pattern configurations were developed in this study. Different combinations of trigonometric formulations were used to attain the required surface perturbations. These formulations are obtained by multiplying two patterned geometrical frequencies. The first pattern frequency refers to the change in amplitude and number of radial lobes while the second pattern frequency multiplier changes the frequency along the depth of the tube. Fig. 1 illustrates the formulation of developed CBC patterns.

For the radial pattern frequency Eq. (2.1) provides the parametric equation with a parameter θ which ranges from 0 to 360;

$$\lambda_1 = R - \eta * \cos(\zeta * 2\pi * \theta) \tag{2.1}$$

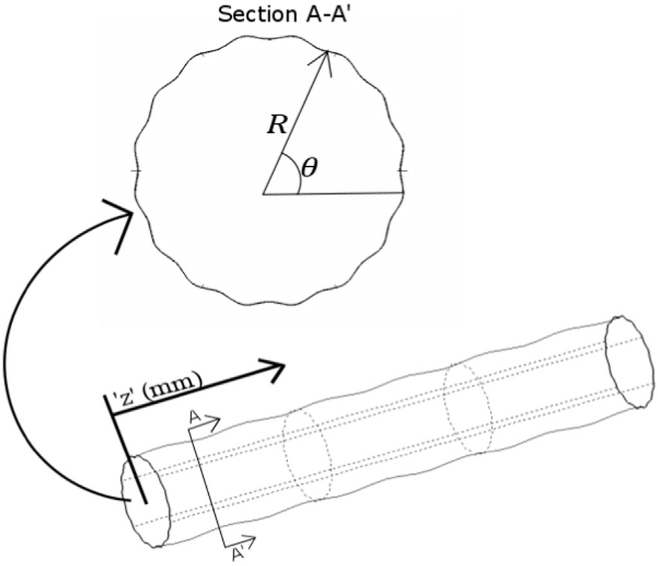

Fig. 1. CBC patterns description.

where R is effective radius of tube, 2ζ is the number of radial lobes and η is the amplitude of radial lobes. The mathematical formulation for longitudinal frequency which varies along the depth is described in Eq. (2.2) as

$$\lambda_2 = \left(\left(\left(\cos\frac{(\pi(Z))}{a_1}\right)+1\right)*2\right) + \left(\left(\sin\frac{(\pi(Z))}{a_2}\right)*\kappa\right) \tag{2.2}$$

where z is the dimension of tube along the depth and κ is a multiplying factor varying from 0.1 to 0.45, a_1 and a_2 are dividing factors which vary from 12.5 to 14.5 and 25 to 40 respectively further discussed in Section 4.3. Table 1 describes a selected few of the CBC patterns with the values of design variables chosen for this study. Almost 72 CBC patterns were created by using the mathematical formulations described in Eqs. (2.1) and (2.2).

3. Numerical simulation

3.1. Model setup

The beam of a length 600 mm beam was modelled with cross-section of 100 mm diameter, 'D' and a thickness 't' of 1.7 mm. In the setup shown in Fig. 2, a mass of 800 kg with an impact velocity of 15.67 m/sec and a top rigid link with a constrained motion is used. A planar rigid wall is used at the bottom of the model. The impact velocity was kept at 15.56 m/s (56 km/h) which is the representative velocity of most crash tests [21]. Experimental results showed that the peak load is nearly constant for the range of impact velocities during an axial impact [29]. Due to the plastic deformation, there is a marginal difference between the load-

Table 1
Design variables of selected (4/72) CBC patterns.

Name	Radial frequency λ_1			Longitudinal frequency λ_2		
	R (mm)	η (mm)	2ζ	a_1	a_2	κ
CBC Ref. Model	50	–	–	–	–	–
CBC 1	50	1	40	12.5	25	0.1
CBC 4	50	1	32	12.5	25	0.1
CBC 7	50	1	24	12.5	25	0.1
CBC8	50	1.5	24	12.5	25	0.1