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Energy absorption improvement of circular tubes with externally press-fitted ring around tube surface subjected under axial and oblique impact loading

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ABSTRACT

The dynamic axial and oblique crushing of circular tubes with externally press-fitted ring around the outer tube surface was investigated numerically using the Abaqus/explicit finite element simulation tool. The study shows how the reinforcement of ring strips fitted around the tube surface have the potential of improving the energy absorption capacity. Crashworthiness parameters such as the mean and peak crushing force, Crush Force Efficiency and specific energy absorption were evaluated for different tube profiles. Effect of slenderness ratio and tube thickness on the collapsed mode and crashworthiness parameters were examined by increasing the number of rings around the tube surface with different ring thicknesses. New collapsed modes were obtained as the ringed circular steel tubes were subjected to dynamic axial and oblique compression. The results obtained from the ringed tubes showed a reasonable percentage increase in the total energy absorption as compared to the conventional circular tubes without rings.

1. Introduction

The improvement of energy absorption capacity of collapsed thin-walled tubes has been the subject of recent research especially for crashworthiness application. This aspect of research is justified because of the high rate of fatalities and injuries recorded during vehicular crashes. The thin-walled tube is a veritable and efficient component incorporated into vehicles not only to protect the occupants from injuries and probable death but also to minimize damage of the vehicle. This can be achieved by designing an efficient tube which has great potentials of converting the high kinetic energy released during accident into plastic deformation energy.

A number of tube geometries of different types have been employed for designing energy absorbing materials for crashworthiness application [1–3]. In [4] the authors performed both an experiment and simulation on the crashworthiness of composite structures and evaluated the effect of geometric features on the crushing behaviour of the tube. They found out that the small corner element was the most efficient in absorbing energy per unit mass compared to the other specimen with longer flanges; also the more contoured the specimen, the higher the measure of the specific energy absorption. Hobbs et al. [5] also studied the effects of structural geometry on crashworthiness of carbon/epoxy composites. Using both circular and square sections, they showed experimentally how the unsupported and pin-supported test section can assess the effects of laminate design for crashworthiness. Investigation has shown that circular thin-walled sections give the most efficient energy absorption capability because of their progressive axial folding [6] and tenable constant operating force. Attempts have been made to improve the energy absorption capacity of circular tubes using composites [7,8], and foam-filled tubes [9–12]. Other methods such as including patterns and grooves on the external surface of circular tubes have been investigated [13,14]. In recent years, Salehghaffari et al. [15] attempted to improve the energy absorption characteristics of circular tubes by making wide grooves from the outer surface of a steel thick-walled circular tube. Their results showed an increase in energy absorption. However, studies showed that most authors investigated quasi-static axial crushing of tubes that produces progressive folding process of thin-walled structure [16,17] while in actual case there is irregular behaviour of the thin-walled tubes due to the dynamic axial and/or oblique crushing of the thin–walled system.

The static or dynamic impact crushing of vehicular structures could either be axial or oblique in nature. The axial crushing of thin–walled tubes have been investigated by a number of authors [18–20]. However, study shows that few authors have investigated both the

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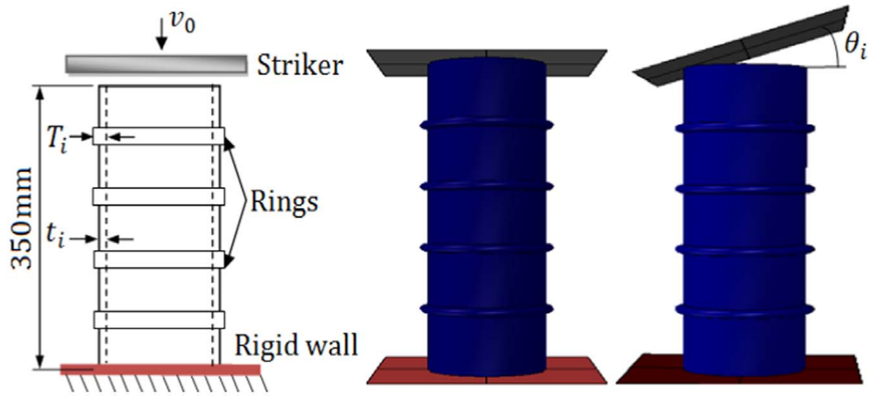

Fig. 1. Geometrical configuration for axial and oblique impact loading.

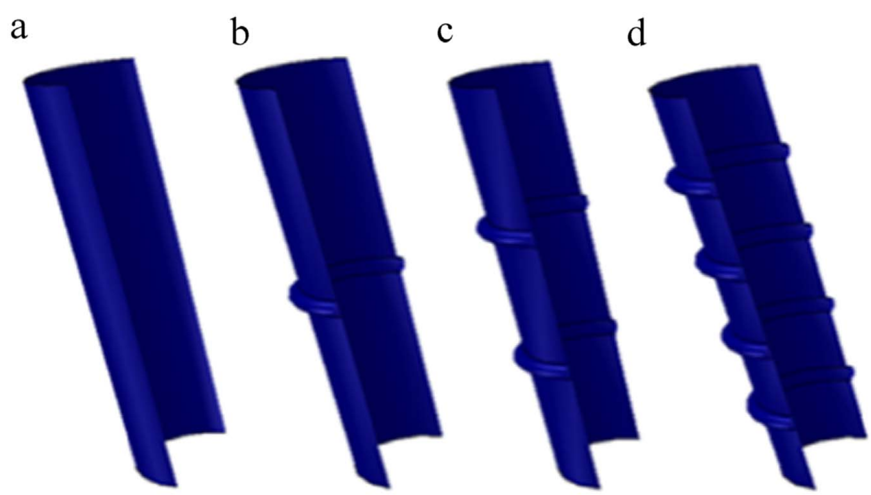

Fig. 2. Schematic of the different structural design profiles (a) NRS0 tube section (b) RS1 tube section (c) RS2 tube section (d) RS4 tube section.

Table 1
Number of rings with the dimensions of tubes and angle of impacts used for study.

No. of rings	Tube length (mm)	Tube diameter (mm)	Ring thickness (mm)			Impacting angle (degree)			Tube thickness (mm)				
			T_1	T_2	T_3	θ_1	θ_2	θ_3	t_1	t_2	t_3	t_4	t_5
0	350	75	–	–	–	10	20	30	0.8	1.0	1.2	1.4	1.6
1	350	75	1.5	2.5	3.5	10	20	30	0.8	1.0	1.2	1.4	1.6
2	350	75	1.5	2.5	3.5	10	20	30	0.8	1.0	1.2	1.4	1.6
4	350	75	1.5	2.5	3.5	10	20	30	0.8	1.0	1.2	1.4	1.6

Table 2
Material properties for the A36 steel hot rolled carbon.

							Material constant [29]				
C_p (J/kg °K)	T_m (K)	T_0 (K)	E (GPa)	$\dot{\varepsilon}_0$ (s^{-1})	ρ (kg/m^3)	υ	A (MPa)	B (MPa)	C	N	M
486	1773	295	200	1	7850	0.26	146.7	896.9	0.033	0.320	0.323

axial and oblique crushing of thin–walled tubes [21,22]. A possible reason for the less attention of the investigation of oblique impact could be because the tube has the tendency to bend when subjected to oblique impact [23] and the consequence is that it lowers the energy absorption capacity.

A very important aspect of recent research is finding ways to reduce the peak crushing force. Different investigations showed improvement in energy absorption but the initial peak forces are still very much higher than their subsequent pair of peak forces. Hao et al. [24] investigated the energy absorption of concentric circular tubes. In their findings, an increase in the thickness of the tubes resulted in the increase in the peak crushing load and mean crushing loads for both high strength steel and stainless steel. This makes them undesirable material used for energy dissipation purpose. However, some authors have attempted to improve the energy absorption as well as to reduce the initial peak load of the crushed tube. Sameer et al. [25] performed a numerical comparison between aluminium alloy and mild steel by adding foam material to the thin-walled tube. Their findings showed that the initial crush load reduces with foam material as compared to those without foam material. A similar result was obtained by [26]. The

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