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Collapse behavior of thin-walled corrugated tapered tubes under oblique impact

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ABSTRACT

Thin-walled structures are used in safety applications such as automotive vehicles and locomotives because of their efficient energy absorption, light weight, and reduced manufacturing cost. The performance of these structures is inhibited under oblique loading conditions. This paper numerically studies the crushing behavior and performance of corrugated tapered tubes (CTTs) as potential efficient thin-walled structures under oblique loading conditions. The proposed CTT design is impacted under 7 different loading angles with a striker mass of 275 kg and 15 m/s velocity. The material assigned to the proposed design structure is AA6060 aluminum alloy. The effect of loading angles on various performance indicators, such as the initial peak force (PF), mean crushing force (MF), energy absorption (EA) and specific energy absorption (SEA) was studied. It was found that increasing the impact angles lead to a reduction in performance, and a reduction of around 54% in EA and SEA was observed when the impact angle increased from 0° to 40°. Moreover, the effect of the geometric parameters on the performance indicators was also investigated. In addition, global bending was found to develop at higher impact angles for CTTs of 80° tapered angles. Finally, it was found that some CTTs can achieve higher SEA relative to their tapered conventional counterparts.

1. Introduction

Thin-walled tubular structures are widely used in the engineering field, specifically for impact energy absorption applications. The lightweight, low manufacturing cost and excellent energy absorption characteristics qualify these structures to be used in applications where safety is vital, such as building cladding surfaces, train and automobile vehicles' chassis (Fig. 1). Thin-walled structures dissipate the impact energy by deforming plastically so the impact energy does not reach the occupants. Because of their vital role in the energy absorption field, there has been extensive research work in the literature on enhancing the performance of these structures under different loading conditions. The research work in the literature mainly studies the various types of structures' geometrical parameters, wall surface patterns, and conical or tapered structural layouts.

There has been a huge focus by researchers on investigating various geometric features of thin-walled structures to improve their overall performance. For instance, many papers have studied the effect of different cross-sections on the energy absorption performance. Structures of circular, rectangular, polygonal, hexagonal and star-shaped cross sections have been investigated [1–4]. Besides studying various cross-sections, researchers examined the effects of thin-walled structures fillers, specifically metallic foams of non-uniform [5–7] and uniform [8–11] density distribution. The results of their work showed that metallic foam fillers improve the overall energy absorption due to their light weight and low initial stress. In addition to foam fillers, the influence of thin-walled structures' wall thickness has been studied extensively. Sun et al. [12] have explored the effect of functionally graded thickness (FGT) on square tubular structures. Similarly, Zhang et al. [13] studied conventional tubular structures of square-cross sections with FGT. Multicellular structures where the tube is divided into multiple cells were also studied widely by researchers. For example, Nia et al. [14] studied multicellular structures of different cross-sections. As well, Tang et al. [15] found that multicellular structures have better energy absorption performance than structures of single cells. Likewise, in their study on structures of multicellular configurations, Chen and

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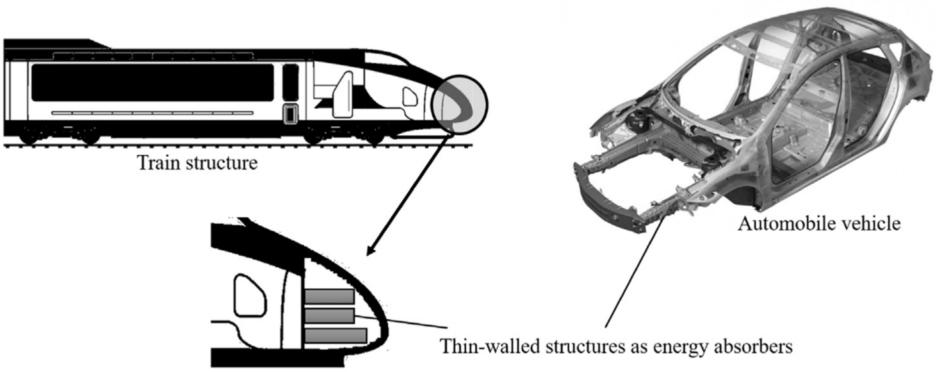

Fig. 1. Application of thin-walled structures in automobile vehicles and trains.

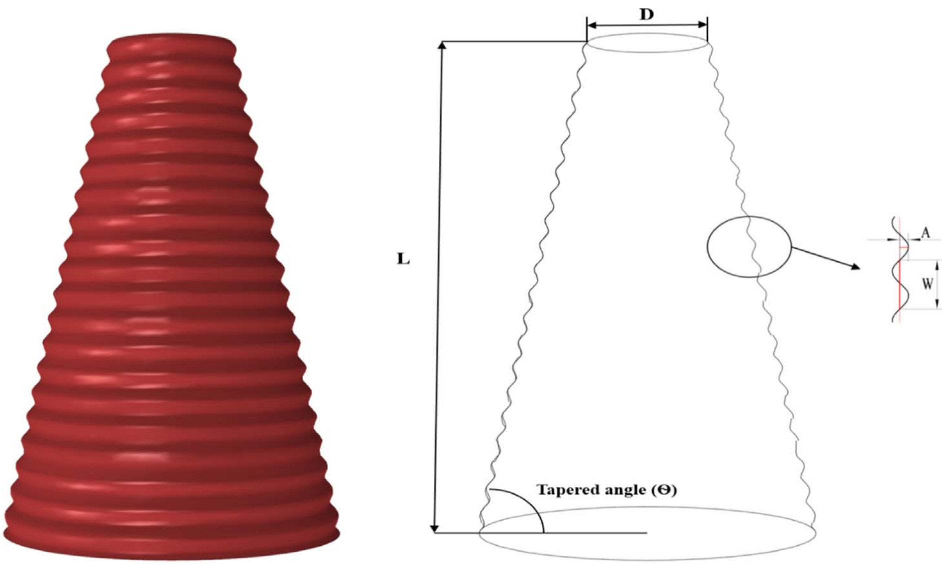

Fig. 2. Corrugated tapered tube profile and parameters.

Table 1
CTT geometric factors and values.

Geometric factor	1st level	2nd level
Amplitude (A)	1 mm	2 mm
Wavelength (W)	10 mm	20 mm
Tapered angle	80°	85°
Thickness (t)	1 mm	2 mm

Wierzbicki [16] had reported an approximate increase of 15% in specific energy absorption when double and triple cellular configurations were adopted instead of a singular one. Additionally, Wu et al. [17] studied tubes of multicellular configurations and found that a 5-cell tubular configuration offers excellent crashworthiness characteristics. Multicellular structures with graded thickness have also been studied, such as the study done by Zhu et al. [18] in which a novel design of a graded honeycomb structure was proposed for energy absorption application. Similarly, Fang et al. [19] investigated multicellular structures of functionally graded thickness, while Zheng et al. [20] studied multicellular structures of laterally varying thickness. Moreover, Zhang and Cheng [21] have shown that multicellular structures have approximately 50–100% higher energy absorption and efficiency than structures filled with foam. Nested tubular systems [22] where one thin-walled structure is nested within another have been explored for their promising potential in energy absorption. Similar systems of bitubular structures [23], square-cells [24], composite sandwich structures [25,26] and tailor rolled blank structures [27] have also been explored for their energy absorption capabilities.

Lately, thin-walled structures with various surface patterns have been the focus of many scientists, and have shown significant enhancement in energy absorption and lowering the initial crushing forces. Song et al. [28] studied structures of rectangular holes patterns (windowed tubes) experimentally and found that these patterns reduce the initial crushing force. Similarly, Nikkhah et al. [29] studied the effect of various shapes of holes' patterns on the energy absorption response of thin-walled structures under different impact angles. Their results have shown that surface holes reduce the initial crushing force, and that square and rectangular holes patterns result in better crushing performance compared to a conventional tube. In addition to windowed structures, Isaac et al. [30] explored new external patterns of press-fitted rings on the structure surface. The results revealed that structures with these patterns have higher energy absorption than regular tubes. Similar to the idea of external ring patterns, Wu et al. [31] investigated the performance of straight tubes with sinusoidal corrugated patterns.