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Dynamic performances of thin-walled tubes with star-shaped cross section under axial impact

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ABSTRACT

Under axial loading, the thin-walled structures will experience severe plastic collapse at the corners. The presented paper focuses on the axial dynamic performances of the thin wall tubes with star-shaped cross sections (S-tube). Firstly, the impact tests of the Aluminum S-tube samples are performed to confirm the accuracy of numerical simulation. Then, a mode classification chart is given based on simulations with tubes of various dimensions. It is found that the slenderness of tube plays an important role in the deformation mode. Besides, the relationship between the deformation mode and energy absorbing performance are discussed through FE method. The specific energy absorption (SEA) of S-tube is slightly better than the polygon tube (P-tube) due to the fact that the deformation mode of S-tube with longer fold length hinders the potential capability of multi-corner tube. Finally, a new design combining the characteristics of S-tube and traditional polygon tube (P-tube) is proposed. The numerical result shows that SEA of the new design is 40% higher than that of P-tube.

1. Introduction

Traffic accidents always raise the concern of automobile crashworthiness [1]. With the development of light weight automobile, new structure with high crashworthiness becomes essential. Usually, car structures for energy absorption must have high values of mean crushing force (P_m), crushing force efficiency (CFE) and specific energy absorption (SEA) [2–6].

Up to now, a lot of researchers have made their contributions to new structure design of energy absorbing components, such as circular tubes [2,4,7], square tubes [6,8–10], tapered tubes [6,11], foam fillers [4,12–15], multi-cell columns [16–19], and polygonal columns [20–23] with methods of experimental test [14,24–26], numerical simulation [3,25,27–29] and theoretical calculation [9,27,28,30,31]. Many results can be applied to the structural design of practical engineering. Thin-walled metal tubes with polygonal cross section are most common designs for energy absorption [23,25]. Wierzbicki and Abramowicz [32] proposed the theoretical mechanism of the square column and analyzed its dynamic performances. It was reported that the rolling and extensional deformation in the corner region has a significant contribution to the total energy dissipation under axial impact. Yamashita et al. [21] reported that the crush strength of thin-walled tubes with polygonal cross section increases with the number of corners up to 11. By welding two or three longitudinal ribs inside the tube, Kim et al. [16] improved the energy absorption efficiency of square tubes by 1.9 times. The literature reports show that the collapse of corners of the multi-cell thin-walled tubes had a remarkable influence on the energy absorption efficiency [16,21,22,32,33], and several researchers [10,34] proposed that the energy absorption ability can also be improved by enhancing the strength of the edges.

The deformation mode and energy absorption are significantly affected by the corner angle. For polygonal tubes, the highest mean crushing force can be achieved by setting its corner angle within the range of 90° and 120° [21]. Since the corner angle of the polygonal tubes would exceed 120° with the increase of its corner number, it is impossible to enhance the P_m and guarantee a high level of SEA at the same time by simply increasing its number of corners. Tang et al. [35,36] presented a new shape of cross-section named non-convex multi-corner tube, which can keep the corner angle between 90° and 120° while maintaining a large number of corners. Another non-convex multi-corner tube named star-shaped tube was proposed by Fan et al. [37] and was proved that it has similar advantage as the design proposed by Tang et al. [35]. Fan et al. concluded that the non-convex tubes can only improve the energy absorption efficiency in a limited range. And the collapse modes become unstable when D/t (D is the nominal diameter and t is the wall thickness) is greater than a certain value. Liu et al. [36] inserted

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some horizontal ribs in the column inspired by the characteristics of bamboo on the purpose of expanding the validity of the tube with cross section of non-convex. Abbasi et al. [38] investigated the effect of cross-sectional configuration, the wall thickness and material type on energy absorption of a 12-edge polygon, taking the specific energy absorption (SEA) and crush force efficiency (CFE) as the primary standards. The dynamic performance of a laterally corrugated tube proposed by Eyvazian et al. [39] was similar to the star tubes proposed by Fan et al. [37]. Since the folding length of laterally corrugated tube was too long comparing with that of parallel corrugate tube, the load vs. displacement diagrams of laterally corrugated tubes show a high value of crush force but very high fluctuations. In presented work, the relationship between deformation mode and energy absorption ability of the thin-walled star-shaped metal tubes (S-tube) was studied with numerical and experimental methods. Firstly, the impact tests of S-tube were performed to validate the finite element model. Since the non-convex polygon tube is likely to deform in non-compact mode [35,37,38], the second step is to discuss the effects of inward corner number, the wall thickness (t), the column length (L) and nominal diameter (D) on the deformation mode of S-tubes with dynamic simulations. Tube slenderness is considered as the key factor influencing the deformation mode. Then, the deformation characteristics and crashworthiness of S-tubes were compared with those of traditional polygon tube (P-tube). Finally, two polygonal shells were placed at both sides of the S-tubes to decrease the slenderness of thin-walled structure, which can effectively improve the energy absorbing performances.

2. Experiment and simulation

2.1. FE model

According to Tang [35], the corners in the cross section of S-tube can be divided into two types: the convex corner and the

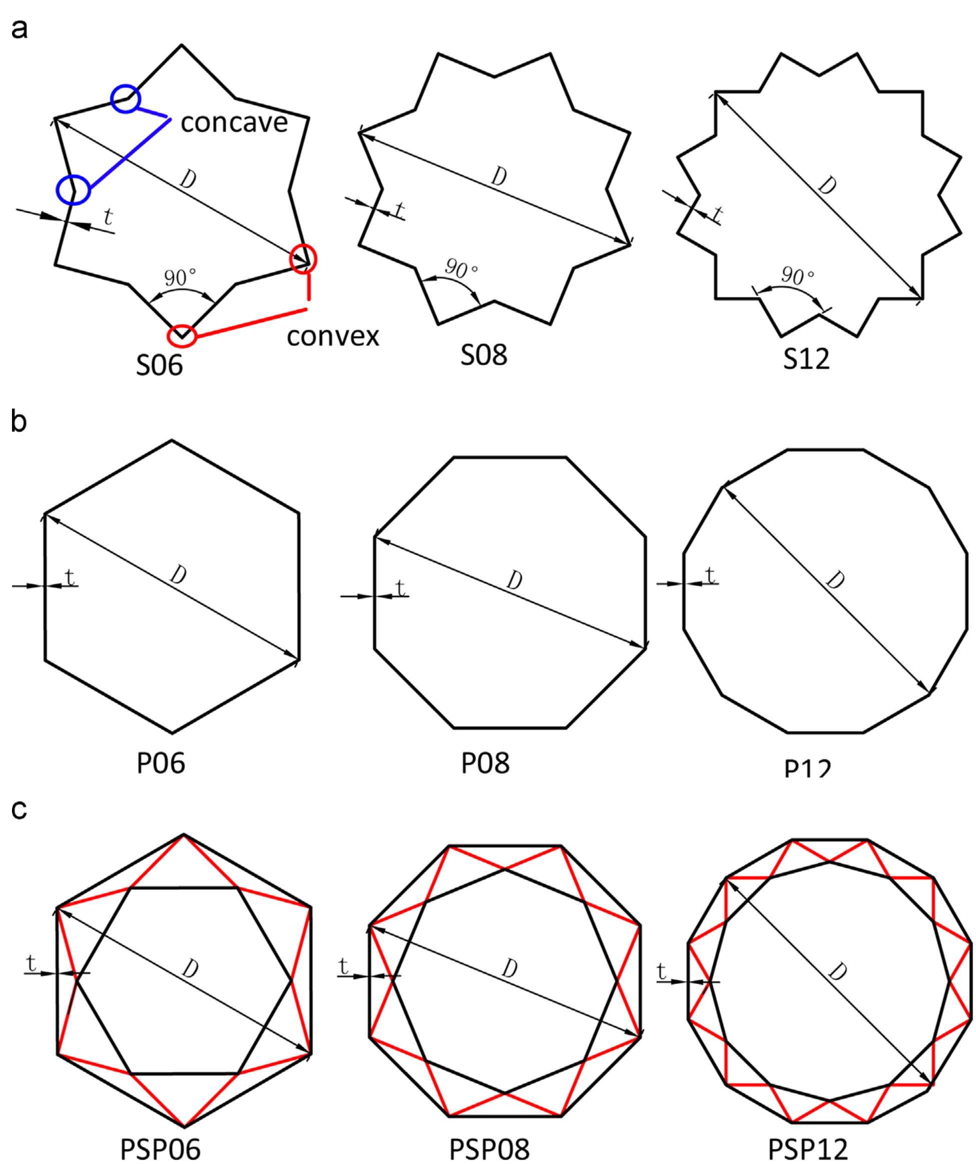

Fig. 1. The sketch of cross section of all tubes.