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NUMERICAL ANALYSIS AND THEORETICAL PREDICTION OF AXIAL CRUSHING CHARACTERISTICS OF MIXED THIN-WALLED TUBES WITH DUAL-VARIABLE ATTRIBUTE

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ABSTRACT–Thin-walled structures with varying thickness (single variable attribute) had been proven to be able improve energy absorption characteristics. In order to further study the energy absorption characteristics of thin-walled structures whose material properties changed as the thickness changing, a novel type of mixed thin-walled tube with axially-varying thickness and material were proposed in this paper. The finite element (FE) model was validated under axial quasi-static loading firstly, and seven groups simulation models of thin-walled tubular structure were established. The simulation results showed that the dual-variable attribute tubes can ensure high energy absorption and reduce the initial peak crushing force effectively in the crushing process. Furthermore, the maximum crushing force efficiency of steel-aluminum mixed tube can reach 2.77, while the aluminum mixed tube increased the crushing force efficiency to 1.24. Subsequently, a analytical model for dual-variable attribute tube was established and the theoretical mean crushing force calculation formula can be derived. The simulation and theoretical results were wirelessly close, except that the error of SUT5 was about 11 %. Therefore, the theoretical prediction results were in good agreement with the simulation results, and the theoretical prediction method can provide some reference for the design of double variable tube.

KEY WORDS : Dual variable properties, Steel-aluminum mixed, Quasi-static crushing, Thin-walled tube, Finite element analysis

1. INTRODUCTION

The thin-walled structures are featured by being cost-efficient, lightweight and crashworthy which have been extensively utilized in the vehicle engineering. Meanwhile, their amazing performance in energy absorption and remarkable mechanical properties are widely used in aerospace, transportation and package engineering (Abramowicz, 2003; Airoldi and Janszen, 2005; Fang *et al*., 2017). In the past decades, enormous research efforts were put in designing the thin-walled tubes with diversity cross-sectional shapes (Baroutaji *et al*., 2017), for instance, square (Guan *et al*., 2018; Zhang *et al*., 2014), circular (Li *et al*., 2016a; Reuter *et al*., 2017), hexagonal (Hou *et al*., 2007; Tarlochan *et al*., 2013) tapered (Yin *et al*., 2014), and gradient tubes and gradient tubes and gradient tubes (Yin *et al*., 2013; Yu *et al*., 2018), etc. Furthermore, Nia and Hamedani (2010) studied circular, square, rectangular, hexagonal, triangular, pyramidal and conical tubular structures experimentally and numerically and the result showed that the circular cross-section tube has the strongest energy absorption capacity in those tubes.

Recently, thin-walled tubes with more complex sections (multi-cell) become the focus of attention and have been widely studied for improving the crashworthiness. In order to describe the collapse phenomenon mechanically, Chen and Wierzbicki (2001) derived Simplified Super Folding Element (SSFE) by investigating the behavior of single-cell double-cell and triple-cell, and the theoretical solution was highly consistent with numerical predictions. Fourier series expansion was used to generate a series of novel sectional configurations of tube by Wu *et al*. (2017). Multi-cell tubes with triangular and Kagome lattices were designed and manufactured by Hong *et al*. (2014) to reveal the progressive collapse mode of thin-walled multi-cell tubes. Wu *et al*. (2016) proposed rectangular multi-cell thin-walled tubes and obtained optimal five-cell tube by NSGA-II. Circular multi-cell and embedded multi-cell thin-walled tubes were systematic discussed by Zhang and Zhang (2014) and Zhang *et al*. (2017). Basing on the idea of changing the cross-section, foam-filled thin-walled tubes were proposed, such

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