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Crushing analysis and multiobjective crashworthiness optimization of honeycomb-filled single and bitubular polygonal tubes

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ABSTRACT

Honeycomb-filled tubes have recently gained attention for their enhanced energy absorption capacity. This paper firstly investigates the energy absorption characteristics of honeycomb-filled single and bitubular polygonal tubes (HSBPT) by nonlinear finite element analysis through LS-DYNA. By employing a six-level judgement method, we find that both of the honeycomb-filled single and honeycomb-filled bitubular tubes with enneagonal configuration have very excellent energy absorption characteristics among the considered cases. Next, the HSBPTs with enneagonal configuration are optimized by adopting multiobjective particle swarm optimization (MOPSO) algorithm to achieve maximum specific energy absorption (SEA) capacity and minimum peak crushing force (PCF). During the process of multiobjective optimization design (MOD), accurate metamodels of SEA and PCF of the HSBPTs with enneagonal configuration are established to reduce the computational cost of crash simulations by finite element method. Numerical experiments show that the quartic polynomial functions of SEA and PCF are the suitable metamodels for both honeycomb-filled single and bitubular enneagonal tubes.

1. Introduction

Nowadays thin-walled structures have been widely used as energy absorber for their excellent energy absorption capacity, extraordinary light weight and relatively low price in automotive, aerospace, military and other industries [1,2]. For the extensive practical application of the thin-walled tubes, their energy absorption characteristics have been studied by experimental, theoretical and numerical methods during the past decades. Alexander [3] investigated the axial crushing of circular tube and developed an approximate theoretical expression of the mean crushing force in 1960. After that, Wierzbicki and Abramowicz [4] proposed the Super Folding Element theory and gave the theoretical predictions on the axial mean crushing strength of rectangular tubes. Abramowicz and Wierzbicki [5] predicted the axial mean crushing strength of multicorner thin-walled tubes. Abramowicz and Jones [6] conducted over 120 axial crushing tests on circular and square steel tubes loaded either statically or dynamically. Theoretical predictions for circular and square tubes under either static or dynamic loading condition were developed and these theoretical solutions showed excellent agreement with experimental results. Zhang and Huh [7] investigated the energy absorption characteristics of regular polygonal tubes under dynamic axial loading by the nonlinear finite element code LS-DYNA. It should be mentioned that the above investigations mainly concentrated on the crash behaviors of empty tubes subjected to axial loading.

In addition to these thin-walled tubes, metal honeycomb is also widely used as an excellent energy absorber with highly light weight. Due to its excellent energy absorption property, metal honeycomb has been extensively studied by a lot of previous researchers [8,9]. For example, the axial crushing strength of hexagonal honeycomb structure was calculated by Wierzbicki [10] by using the Super Folding Element theory. The theoretical solution showed an excellent correlation with the experimental results. Wu and Jiang [11] conducted the experiments for six types of aluminum honeycomb structures under axial quasi-static and dynamic loading. It can be found from their test results that the dynamic axial crushing strength is usually higher than that of the quasi-static one. Moreover, a large amount of numerical work [12–16] has been carried out on honeycomb structures by nonlinear finite element code such as PAM-CRASH, ABAQUS Explicit and LS-DYNA. From the above researchers work, we can easily find that the multi-cell aluminum honeycomb can absorb lots of impact energy with light weight during its axial crushing.

In order to further enhance the energy absorption capacity of empty tubes, honeycomb is considered to be filled into these tubes.

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