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RESEARCH PAPER

Crashworthiness analysis and optimization of standard and windowed multi-cell hexagonal tubes

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Abstract

Recently, multi-cell structures have received increased attention for crashworthiness applications due to their superior energy absorption capability. However, such structures were featured with high peak collapsing force (PCL) forming a serious safety concern, and this limited their application for vehicle structures. Accordingly, this paper proposes windowed shaped cuttings as a mechanism to reduce the high PCL of the multi-cell hexagonal tubes and systemically investigates the axial crushing of different windowed multi-cell tubes and also seeks for their optimal crashworthiness design. Three different multi-cell configurations were constructed using wall-to-wall (WTW) and corner-to-corner (CTC) connection webs. Validated finite element models were generated using explicit finite element code, LS-DYNA, and were used to run crush simulations on the studied structures. The crashworthiness responses of the multi-cell standard tubes (STs), i.e., without windows, and multi-cell windowed tubes (WTs) were determined and compared. The WTW connection type was found to be more effective for STs and less favorable for WTs. Design of experiments (DoE), response surface methodology (RSM), and multiple objective particle swarm optimization (MOPSO) tools were employed to find the optimal designs of the different STs and WTs. Furthermore, parametric analysis was conducted to uncover the effects of key geometrical parameters on the main crashworthiness responses of all studied structures. The windowed cuttings were found to be able to slightly reduce the PCL of the multi-cell tubes, but this reduction was associated with a major negative implication on their energy absorption capability. This work provides useful insights on designing effective multi-cell structures suitable for vehicle crashworthiness applications.

Keywords Crashworthiness optimization · Trigger · Windowed multi-cell tube · Energy absorption · Dynamic collapsing

1 Introduction

Thin-walled tubes have been widely utilized as efficient energy absorbers in vehicles' structural frame to reduce the harmful influences of impact loading and to protect the passengers. Peak collapsing load (PCL) and specific energy absorption (SEA) are the most important responses of energy absorbing structure for vehicle crashworthiness applications. Generally, high SEA and low PCL are preferred to ensure the lightweight design of the vehicle and the safety of the passengers. Over the past years, there was a growing interest in the crashworthiness field where the crush responses and deformation modes of various structures under quasi-static and dynamic loads were investigated using numerical, analytical, and experimental methods (Niknejad and Bonakdar 2015; Niknejad and Orojloo 2016; Zahran et al. 2018; Esa et al. 2017; Estrada et al. 2018a, 2018b, 2019; Taghipoor and Noori Mohammad 2018; Taghipoor and Damghani Nouri 2018a, 2018b; Taghipoor et al. 2020a; Tran et al. 2020; Baroutaji et al. 2021). For example, DiPaolo et al. (2004) carried out an investigation on the compression behavior of steel square tubes under quasi-static loading. Ahmad and Thambiratnam (2009) studied the energy absorption ability

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