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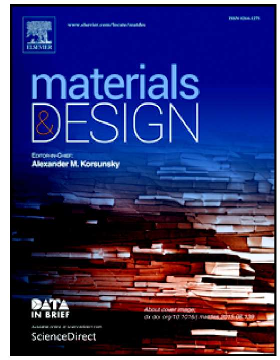

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Feng Xiong, Dengfeng Wang, Shengwen Yin

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Optimization analysis of novel foam-filled elliptical columns under multiple oblique impact loading

Feng Xiong[1,2], Dengfeng Wang[1], Shengwen Yin[3]

1. State Key Laboratory of Automotive Simulation and Control, College of Automobile Engineering, Jilin University, Changchun, 130022, China;

2. Department of Mechanical Engineering, The University of Michigan, Ann Arbor, MI, 48109, USA;

3. State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, 410082, China

***Corresponding author**：Feng Xiong, State Key Laboratory of Automotive Simulation and Control, College of Automobile Engineering, Jilin University, 5988 Renmin Street, Changchun, 130022, China; Email: 471607250@qq.com; xiongfeng15@mails.jlu.edu.cn; fxiong@umich.edu.*

Abstract

Thin-walled columns have been widely employed as energy absorbers for vehicle structures due to their dramatic merits of high energy absorption to weight ratios. Meanwhile, columns filled with low-density metal foams have demonstrated notable improvement on energy absorption capabilities compared with their empty counterparts. Accordingly, the present study aims to investigate and optimize the crashworthiness characteristics of novel foam–filled elliptical column (F-EC) under multiple oblique impact loading. More specifically, the finite element (FE) models of hollow and foam-filled elliptical columns (H-EC, F-EC) are first built and validated against theoretical and experimental outcomes. On this basis, a detailed crashworthiness comparison between the elliptical columns (ECs) and the circular columns (CCs), including hollow and foam-filled columns (H-CC, H-EC, F-CC, F-EC), reveals the superiority of F-EC relative to others on overall crashworthiness characteristics under multiple oblique impact loading. Next, a Taguchi-based design of experiment (DoE) is implemented to investigate the impact of column parameters of F-EC, including the sectional ellipticity *e*, the column thickness *t* and the foam density ρ_f, on the column peak crushing force under axial impact loading (PCF^0) and overall specific energy absorption under multiple oblique impact loading (SEA_θ). Subsequently, the Taguchi method coupled with grey relational analysis (GRA) is utilized to explore the optimal design of F-EC for maximizing SEA_θ and minimizing PCF^0 simultaneously, which is then verified through a detailed crashworthiness comparison between the optimized design and the original design. The optimal F-EC reveals more superior crashworthiness characteristics relative to the original design and thus demonstrates enormous potential as a candidate energy absorber particularly under multiple oblique impact loading.

Key words: Multi-objective, crashworthiness; foam-filled; elliptical columns; oblique impact loading; Taguchi method; grey relational analysis;

1 Introduction

The past decades have witnessed explosive growth of car ownership worldwide, which has inevitably brought severe challenge to energy reservation, environmental protection and road safety [1, 2]. On one hand, the vehicle structures are required to be lightweight designed or optimized to contribute to energy conservation and environment protection, while on the other hand, the vehicles feel increasingly powerless to get rid of obesity and overweight due to the ever-increasing public appeals for vehicles with more superior crashworthiness safety and more diversified functions. Hence, how to make a balance between light weight and crashworthiness safety for vehicles is a complex task confronting engineers and researchers worldwide and worth of more in-depth studies. For this reason, thin-walled structures have drawn extensive attention recently due to their simultaneous merits of light weight yet high energy absorption capacity [3-7].

To fully aware of the crushing mechanism of thin-walled structures and make full advantage of their energy absorption potential, substantial studies have been carried out in literature from experimental [4, 8-14], theoretical [4, 12, 15-18] and numerical [4, 8, 9, 11, 19, 20] aspects. According to a detailed review of the literature, major findings concerning optimization for thin-walled columns could be roughly summarized as follows:

(1) The cross section of thin-walled columns reveals significant impact on energy-absorbing characteristics. Toward this regard, most common cross sections, i.e. triangular [21-23], square [3, 5, 24], hexagonal [25, 26], octagonal