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Theoretical and experimental studies of the instantaneous folding force of the polyurethane foam-filled square honeycombs

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ABSTRACT

This paper presents a theoretical formula to predict the instantaneous folding force of a polyurethane foam-filled square column as a single unit of square honeycombs under axial loading. For this purpose, sum of the dissipated energy rate under folding deformations of the square column and the dissipated energy rate of polyurethane foam compression was equated to the work rate of the external force on the structure. The dissipated energy rate of compression and deformation of polyurethane foam was obtained by presenting a new deformation model and through the reduced volume ratio. The final formula obtained, reasonably predicts the instantaneous folding force of the polyurethane foam-filled square column. Finally, according to the calculated theoretical relation, the instantaneous folding force of the foam-filled square column was sketched versus the axial displacement and compared to the experimental results, which showed a good correlation.

1. Introduction

Increasing the specific absorbed energy (SAE), of structures (especially thin walled structures) has been one of interesting regions for researchers and foam filling of thin walled structures is one way to solve this problem. Researches which consider the effects of foam filling on the behavior of the structures include a large group of foams, especially polymeric and metallic foams [1]. These ultra-light porous materials like honeycombs possess many exceptional mechanical properties like high specific rigidity and high impact energy absorption capacity at very low weight, stable deformation mode and adaptation to loading condition during deformation, etc. [2]. Among honeycomb properties, its folding behavior under axial loading is the most important, since the highest portion of the absorbed energy occurs during this mechanism [3].

In recent decades, many researchers have investigated the honeycomb behavior under various loadings. Wierzbicki and Abramowicz introduced Basic Folding Mechanism (BFM) and calculated the average folding force of a square column based on this theoretical model of deformation [4]. Then, they carried out experimental and theoretical investigations on the crushing process in polyurethane foam-filled square columns [5]. Liaghat and Alavinia compared the theoretical and experimental results and evaluated the analytical relations [6]. Chen and Wierzbicki analytically calculated the mean folding force in a multi-cell square column [7].

A kinematics existence condition for continuing shock propagation in aluminum foams was established by Reid et al. [8]. Santosa et al. performed comprehensive experimental and numerical studies on the crush behavior of aluminum foam-filled sections undergoing axial compressive loading [9]. Salimi et al. conducted a parametric study and numerical analysis on empty and foam-filled thin-walled tubes under static and dynamic loadings [10]. Zarei and Kroger conducted several axial impact tests on empty and foam-filled square columns [11]. Song et al. investigated the interaction effect between aluminum foam and metallic hat sections under axial loading [12].

Niknejad et al. calculated a theoretical formula to predict the maximum folding force during the folding process in single-cell square honeycombs [13] and then calculated the folding angle variations and the instantaneous folding force in the hexagonal columns [14].

Reviewing of the literature on the folding behavior of columns and honeycombs revealed that the average folding force in empty and foam-filled single-cell columns has been calculated theoretically. In this work, the instantaneous folding force of the first fold creation in a polyurethane foam-filled square column was calculated. On the other hand, the instantaneous folding force of the first

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