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Crush behavior optimization of multi-tubes filled by functionally graded foam

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ABSTRACT

Crush behavior of different arrangements of multi-tubes filled by functionally graded foams (FGF) are evaluated in this study. Our study shows that the energy absorption of FGF filled multi-tubes is higher than their equivalent multi-tubes filled by uniform foams. Also, the results show that the type of function employed for grading foam has significant effect on their crush response. In this study, multi-objective optimization was carried out using geometrical average and multi-design objective (MDO) methods. The results give new design ideas under axial loading to improve energy absorption performance of FGF foam-filled tubes.

1. Introduction

Thin-walled tubes built with ductile metal could be subjected to a wide range of deformation modes and various loading conditions. Recently, thin-walled structures have been used in transportation and aerospace industry as crush energy absorber due to their efficient load absorption to material volume ratio. Over the past decades, in order to obtain the critical forces, progressive collapse modes and the energy absorbing properties, considerable investigations have been established to study the compression behavior of thin walled structures [1–4]. Also, various methods have been used to dissipate crash energy, and these methods include multiple-cell structures and testing different materials [5].

A distinctive feature of metallic foam is the energy absorption during the plastic deformation stage, when it undergoes large plastic deformations at a nearly constant load. Axial compression behavior of square and circular steel tubes filled with aluminum foam was investigated by Seitzberger et al. [6]. In their study, it was indicated that the interaction between foam and tube wall increases the absorbed energy and changes the deformation mode. Hanssen et al. [7,8] discovered that the foam lateral movement interaction with tube side walls increases the interaction between foam and tube wall. Consequently, a foam filled tube was presented that has better energy absorption characteristics than superposition of individual foam and tube.

Functionally graded foam (FGF) is a relatively new class of non-homogeneous material configuration, in which micro-scale cells varied continuously in a specific gradient pattern. The mechanical property of the foam depends on its density. This property will vary with location in the porous structure. Thus, density variation of foam is able to improve the energy absorption capability. It is well known that proper selection of tube geometry and metallic foam gradient density function affects the amount of energy absorption in the foam-filled tube. However, producing FGF is more complex than uniform density foam (UDF). Kieback et al. [9] developed manufacturing technique to produce a FGF under laboratory conditions.

In order to improve the crashworthiness of foam-filled tubes, the energy absorption characteristics of two kinds of functionally lateral graded foam-filled tubes was investigated in the study of [10]. The results were obtained by optimization and indicate that the optimal FGF filled tube performs more excellent energy absorption characteristics than the ordinary uniform one. A new type of foam-filled thin-walled structure called FGF-filled tapered tube proposed by Yin et al. [11]. The various designs of FGF were compared using the new multi-objective crashworthiness optimization method.

This paper introduces a novel layered FGF filled single and multi-tube models and predicts their crush behavior under quasi static loading conditions. The results were checked with experimental results of energy absorption characteristic of UDF to validate the results of finite element (FE) model of the proposed layered FGF. Also, to determine their effect on the crush energy

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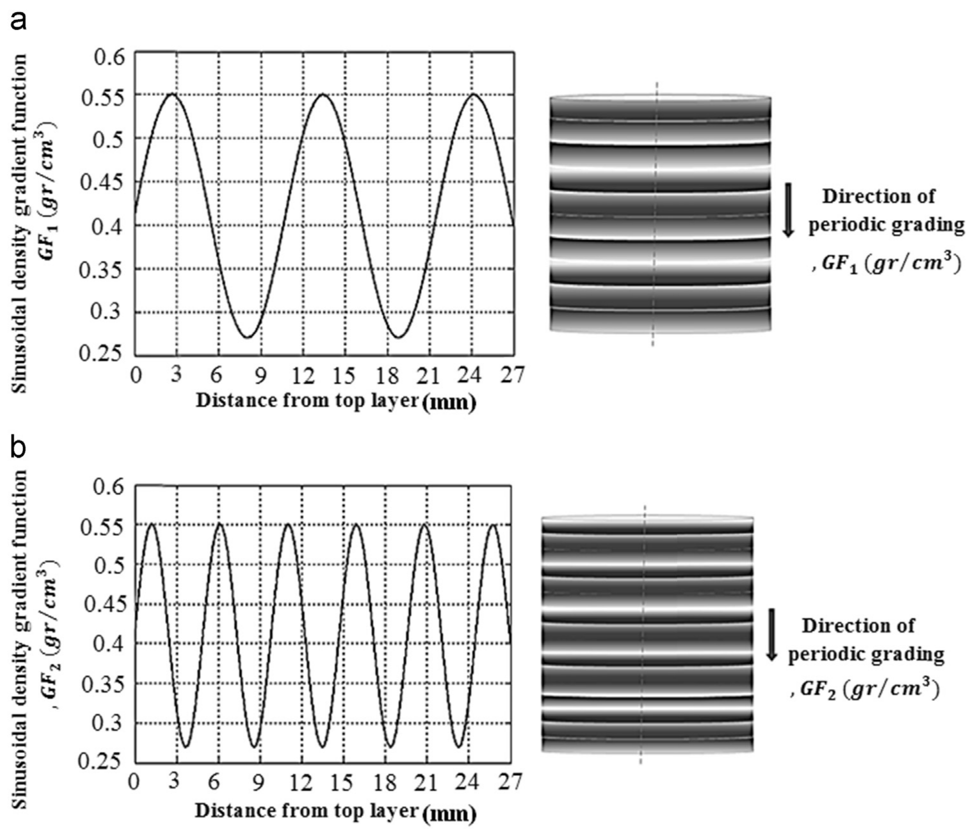

Fig. 1. Variation of density vs. distance for axial grading. (a) GF_1: Sinusoidal function (with 5 extremum point), (b) GF_2: Sinusoidal function (with 11 extremum point).

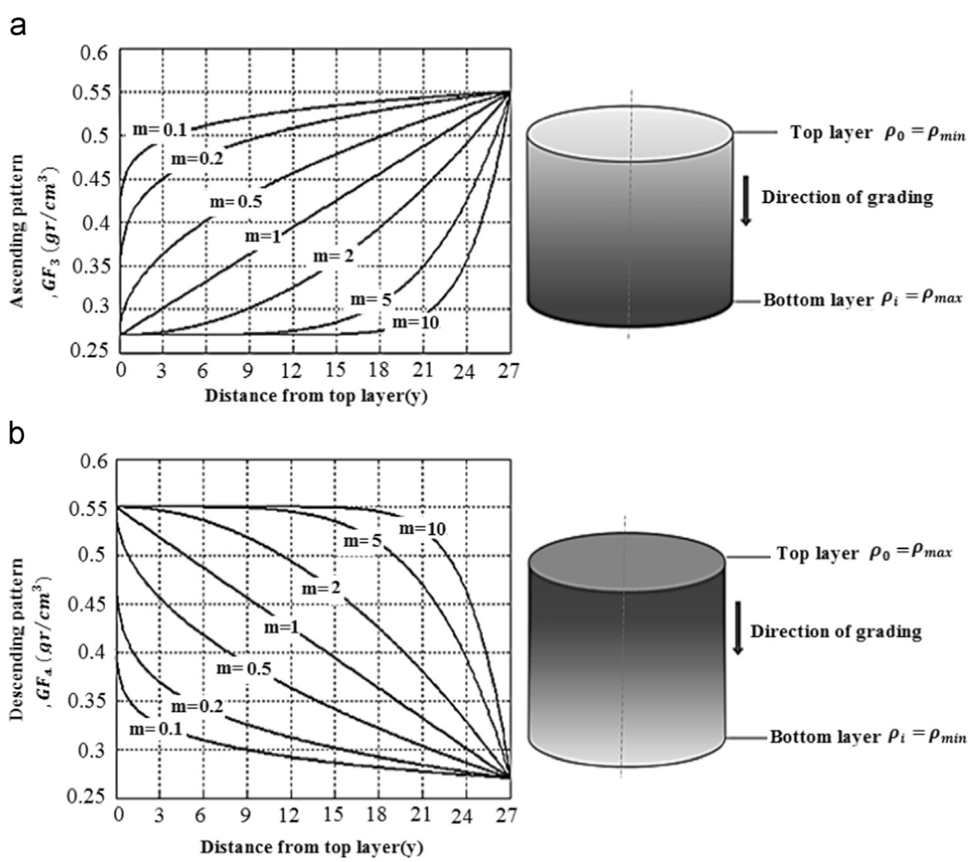

Fig. 2. Variation of density vs. distance for axial grading. (a) GF_3: Ascending pattern, (b) GF_4: Descending pattern.