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Energy absorption performance on multilayer expanded metal tubes under axial impact

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ABSTRACT

The performance of expanded metal tubes was studied under axial impact loading. Despite their low weight, expanded metal sheets have high energy absorption capacity. In order to evaluate the crashworthiness of the tube and to achieve maximum energy absorption, the collapse mechanism of the tube was experimentally examined considering the direction of the cells. The effect of the cell size of the expanded metal sheet, the thickness of the tube and making the absorber a multilayer on the energy absorption and the behavior of the absorbers was numerically investigated. Results demonstrated that the tubes with zero degree angle cells had a symmetric collapse mechanism. Increase in the size of the cells decreased the peak crushing force and the energy absorption capacity. It was observed that increasing the thickness of the tube and making the absorber a multilayer, will have significant effect on the initial maximum crushing force and energy absorption capacity and making the absorber a multilayer improves the crushing efficiency.

1. Introduction

The use of thin-walled structures is on the rise in energy absorbers applications. The overall performance of this type of structures under various loading conditions has improved. Thin-walled structures have a high energy absorption capacity, therefore, they are used as energy absorbers in various industries. Bumpers and absorbers dissipate the kinetic energy of the impact through collapse of the structure and plastic work. Such bumpers are irreversible and cannot be reused after deformation. Therefore, studies are mainly focused on material properties, geometric parameters, and the presence or absence of defects in the structural behavior aiming at achieving higher energy absorption capacity [1–6].

Zye Yang et al. [7] investigated the energy absorption in circular tubes under impact loading. The average crushing length depended on the strain rate and stiffness of the material. It was observed that during buckling, the peak force significantly depended on the strain rate, and during folding, the peak force had a decreasing trend. Decreasing the thickness of the tube is an efficient method of reducing the average crushing load while it does not reduce the maximum crushing load.

The buckling phenomenon in impact loading has to be addressed. Buckling in a structure under impact loading causes the structure to undergo asymmetric collapse which reduces the energy absorption capacity. Accordingly, some studies have been performed on buckling of structures and the failure force under impact loading [8,9].

Huang et al. [10] numerically studied the cylindrical high-strength steel sheets with an elliptical hole under impact loading. The effect of the elliptical hole in the sheet wall on the energy absorption capacity and collapse mechanisms was examined.

Djamaluddin et al. [11] optimized the foam-filled tubes under axial and transverse impact loading. They studied the failure in three different energy absorber structures so as to achieve the suitable peak and mean force with maximum energy absorption.

Jie song et al. [12] introduced patterned windows in tubes with square cross sections with the aim of reducing the weight of the structure. Tubes were investigated under compressive forces. Tests revealed that the tubes with patterned windows outperformed the conventional tubes, greatly decreased the initial peak force, and increased the amount of energy absorbed.

Xiong Zhang et al. [13] investigated the energy absorption specifications of regular polygonal columns and angled elements under axial dynamic loading. The effects of the angle of the elements on deformation and average force were studied. Their experiments revealed various deformation mechanisms and provided useful results in the design of polygonal structures.

Niknejad et al. [14,15] presented theoretical equations to predict energy absorption and crushing force from collapsing the foam-filled quadrangle tubes. It was found that the theoretical prediction with

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experimental result is good communication. In addition, theoretical and experimental studies on lateral compression of square column have been carried out and increase in the length and thickness of column increases energy absorption and aluminum column has the ability for higher special energy absorption.

Abdelaal et al. [16] presented numerical simulation of a novel expanded metal tubular structure for crashworthiness application and demonstrated an improved energy absorption characteristics related to the change in the mass of the tubular structure.

Graciano et al. [17–23] were the first to study expanded metal energy absorbers under pseudo-static loading. Studies on this kind of absorber reveal that collapse mechanism and energy absorption capacity depends on the direction of the cells. They conducted experimental and numerical studies to enhance the energy absorption capacity and decrease the initial maximum force of the absorbers. Further studies have been conducted regarding the number of cells in cross section and the type of cross section (circular and square) to enhance the performance of these absorbers.

The basic types of Expanded Metal products are standard, flattened, grating, architectural (or decorative) meshes, and fine meshes. These products have thousands of applications for enclosure, protection, support, decoration, and filtration, including grills, fencing, walkways, furniture, etc. The light weight and strength of Expanded Metal make it an ideal material for a wide range of commercial and industrial security applications. Storefront protectors, stairway and warehouse enclosures, lockers and tool room partitions are among its many uses. Flattened Expanded Metal is manufactured by passing the standard expanded sheet through a cold-roll reducing mill. The result is a smooth, flat and level sheet. Flattened Expanded Metal is used in a variety of specialty applications, such as lawn furniture, book and storage shelves, lamps and lamp shades, fireplace screens, many types of grilles, occasional tables, folding screens, room dividers, and air filtration filters. Standard Expanded Metal is a finished product that comes directly from the press. The strands and bonds are set at a uniform angle to the plane of the sheet. This gives additional strength and rigidity, alongside skid-resistant surface [24].

Hatami et al. [25] presented experimental and numerical investigation of lattice-walled cylindrical shell. In this study, the type of collapse, force-displacement diagrams, the crushing length, and the absorbed energy were investigated. The experimental and numerical results were compared and it was observed, that they were in good agreement.

In the recent years, the behavior of expanded metal tubes under static and pseudo-static loadings has been studied. In this study, the behavior of the absorbers under dynamic and impact loading was investigated. The collapse mechanism of the expanded metal sheets depends on the direction of the cells. An important parameter in energy absorbers is the specific energy absorption (SEA) or energy absorption efficiency. This parameter is obtained by dividing the energy absorbed by the absorber by the absorber mass. Expanded metal tubes are lightweight and can absorb high amounts of energy. Therefore, it can be concluded that this type of absorber has a high efficiency [26].

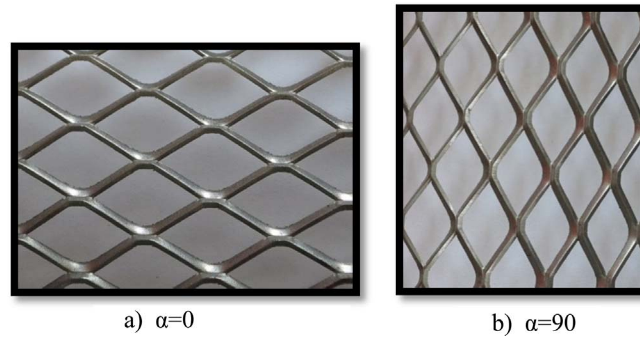

Fig. 1. Cells Direction.

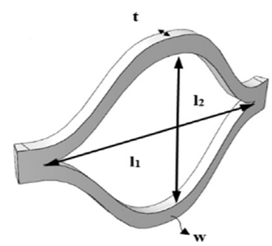

Fig. 2. Cell size.

Fig. 3. Cylindrical tube.

Experimental tests were conducted by the drop hammer setup to assess the collapse mechanism of the tube under impact loading. The cell size, wall thickness and multi-layers were also investigated numerically to enhance the energy absorption capacity of the expanded metal tubes. ABAQUS was used for numerical simulations.

The experimental and numerical studies on expanded metal tubes have been conducted, and it was found that this type of tubes, especially metal tubes perforated with cell angle $\alpha = 0$, have a good performance against the force of impact and can have good performance as an energy absorber.

Fig. 4. Drop Hammer accelerometer sensors [26].