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TECHNICAL ARTICLE

Experimental, Theoretical, and Numerical Investigations into the Compressive Behavior of Multi-layer Metallic Foam Filled Tubes

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This study aims to explore the compressive behavior and energy-absorbing ability of discretely layered foam-filled tubes. Closed-cell zinc, aluminum, and A356 alloy foams manufactured by the casting route are utilized as axial gradient fillers for various configurations of functionally graded structures. The results suggest that the multi-layer foam-filled tubes reveal the multiple quasi-static responses and gradual increase in stress through sequential collapse initiating from the low-density component. By tailoring the foam density and material, the graded foam-filled tubes are promising to regulate the buckling at a desired location and provide better protection. The multi-layer structures generally exhibit superior crashworthiness to the single-layer counterparts, and the maximum quasi-static specific energy absorption of 10.5 J/g is accomplished by the Al–A356/2FT. The plasticity of multi-layer foam-filled tubes can be described by an asymptotic model based on the density, strength and height ratio of uniform constituents. The drop-weight impact behavior of graded structures can be predicted by finite element modeling in LS-DYNA, and the simulation results are in good agreement with the experiments in terms of dynamic response and crushing pattern.

Keywords asymptotic model, compressive behavior, energy absorption, finite element simulation, multi-layer foam filled tube

1. Introduction

Tubular structures are most commonly implemented and recognized as crash absorbers in automotive industries because of their regular axial folding pattern (Ref 1). However, the sudden drop from the yielding strength to the post-buckling strength dramatically reduces the energy absorption efficiency of thin-walled tubes. Metallic foams are also crucial components of crashworthy structures used in a variety of functional applications (Ref 2, 3). These materials show outstanding physical and mechanical characteristics, including low density, high specific stiffness, and strength to weight ratio (Ref 4). The exceptional energy absorption provided by closed cell metallic foams is accomplished through considerable plastic deformation at a roughly steady stress under compressive loading (Ref 5). Lightweight materials such as aluminum foams can be used as fillers to increase the post-buckling strength and deformation stability of tubular structures (Ref 6, 7). To meet the growing requirements of lightweight and vehicular safety, functionally graded foams (FGFs) have been recently developed, while providing higher specific energy absorption (*SEA*) and outperforming the uniform counterparts (Ref 8-10). It is more conveniently produced and employed in engineering for functionally graded foam-filled tubes (FGFTs) with a layered core compared to continuously graded structures (Ref 11).

It is now well established from numerous studies that the mechanical performance of closed-cell metallic foams depends on the parent material features and microstructure parameters such as porosity, strut aspect ratio, size, and geometric configuration of cells (Ref 3, 5, 9). Some investigations on commonly used cellular metals have indicated an increment of dynamic crushing strength compared with the quasi-static condition (Ref 5, 12). However, there have been inconsistent reports on the strain rate sensitivity of metallic foams, which to date have not been elucidated. Deshpande and Fleck (Ref 13) suggested that aluminum foams are almost strain rate insensitive for impact velocities up to 30 m/s. The increasing use of metallic foams as energy absorbers in a wide range of protective applications requires the entire understanding of their failure mechanisms under impact loading. To survey the dynamic response of porous metals, low-velocity drop weight test is a simple but effective route, in which the hammer impact is achieved by the free-fall or acceleration (Ref 14).

The design and analysis of a crash absorber are generally accomplished through experimental and computational techniques. The computational modeling of compressive response can be performed using theoretical, empirical, or statistical methods; The theoretical models are developed by detecting the collapse mode, simplifying the deformation mechanism, adopting some limited assumptions, and applying the plastic analysis. The empirical models are constructed by adjusting

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