Compressive and Energy Absorption Behavior of Multilayered Foam Filled Tubes

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This article investigates the compressive and energy absorption characteristic of metallic foams and functionally graded foam (FGF) filled tubes containing single-, double-, and triple-layered foams. Closed-cell A356 alloy and pure zinc foams are fabricated by the casting method. The results indicate the preparation of A356 foam with larger bubbles and thinner cell walls and, thereby, lower density and compressive strength compared to the zinc foam. The metallic foams show partially brittle behavior associated with cell walls bending and tearing. The double-layered structures exhibit multiple compression behavior and two distinct plateau regions. The presence of high density zinc foam leads to decreasing the specific energy absorption (SEA) of graded structures. However, the compressive deformation and total energy absorption are significantly affected by the zinc foam. The crash performance of multilayered structures can be controlled by varying the number and material of layers at constant geometric features. The single-layered A356 and double-layered A356-Zn and Zn-A356 structures are considered as the best lightweight crashworthy structures with a combination of high SEA (15.3, 7.7, and 7.3 J/g) and low plateau force (10, 13, and 12 kN). Also, an asymptotic hardening model is developed for the porous metals based on the experimental results.

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I. INTRODUCTION

THIN-WALLED components are commonly used as the most popular form of collapsible energy absorbents due to many important aspects, including superior performance under dynamic loading, cost-effectiveness, high efficiency, and ease of manufacturing and installation. Energy absorbents, such as car bumpers, are easily constructed of tubular parts such as aluminum tubes. Energy absorption normally takes place by extensive folding and bending collapse of the tube wall. Crashworthiness, as the main safety criterion of occupant-carrying vehicles, is the capability of a structure to manage and absorb the force of a serious crash and to reduce death and injury risk of the occupants. In the automotive industry, while a sufficient level of mean crushing force is to be assured, a tubular beam with a large specific energy absorption (SEA) has better safety performance and less weight, which is related to both fuel efficiency and manufacturing cost. In practice, the use of circular components in automobile structures met various difficulties associated with mounting to other structural members. Thus, square tubes have received noticeable attention for the fabrication of automobile components.[1–3]

Nowadays, the interest in lightweight materials has been increasing due to the demand of the transportation industry.[4] In the last 20 years, metallic foams, particularly aluminum alloy foams, with an outstanding combination of mechanical and physical properties, have been developed as a new class of functional materials to limit the effect of crashes in the automotive industry. Generally, the mechanical properties of metallic foams depend on the relative density, macrostructure of cells, and microstructure of cell wall material. Improved energy absorption and high specific stiffness have made aluminum foams far more attractive compared to traditional ones, such as metals. The exceptional crashworthiness provided by these types of cellular structures is accomplished through extensive plastic deformation in compressive loading.[5,6]

The melt foaming process is one of the most common and economical methods for the fabrication of metallic foams, especially for producing large foam blocks.[4,7,8] Applications of aluminum foams in many fields, such as protective engineering, call for further insights into the aspect of energy absorption. Under compression, permanent deformation of cell walls occurs and consumes energy. Aluminum foams show three regimes of deformation in the compression test. Each regime is associated with a mechanism of deformation. The most

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